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The study first defines the essential desirable features of the array. It then briefly describes a number of candidate configurations which can meet these requirements, pointing out their advantages and disadvantages.

The report concludes that such an array is feasible, that it can be implanted with a high expectation of reliability and that it can be a safe and stable structure from which to conduct divers novel and useful scientific experiments.

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A FEASIBILITY STUDY FOR A VERSATILE DEEP SEA, MULTILEG, STABLE, CABLE ARRAY

by

Henri O. Berteaux
and
Robert G. Walden

WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts 02543

March 1981

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Department of Ocean Engineering

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ABSTRACT

The purpose of this study is to investigate the feasibility of designing, building, and deploying a large, stable, multileg, deep ocean cable array with a service life of at least five years, and to assess the cost of such an array.

The study first defines the essential desirable features of the array. It then briefly describes a number of candidate configurations which can meet these requirements, pointing out their advantages and disadvantages.

The study then undertakes an array comparative stability analysis. The Fortran computer program DESADE was used to perform this comprehensive study. Current induced displacements and stress levels of simple and complex arrays were computed using this program. The results thus obtained greatly helped quantify their relative merit.

Based on this analysis and on the array requirements previously defined a candidate array is selected for preliminary design. This design essentially consists of the rational selection of type, size, and materials for the buoys, cables, and anchors of the prototype array. Safety factors compatible with the five years life expectancy are confirmed by additional computer runs, using operational and survival current conditions.

The successful deployment and practical servicing of a deep sea implanted array require careful planning and detailed preparation. The next phase of this study is to outline a deployment scenario, and to indicate the different methods for servicing the array. Power sources and methods of data retrieval are considered. Use of manned and unmanned submersibles is contemplated.

The last phase of the study is an estimate of the cost of the prototype array components.

The report concludes that such an array is feasible, that it can be implanted with a high expectation of reliability and that it can be a safe and stable structure from which to conduct divers novel and useful scientific experiments.

1.0 INTRODUCTION

Scientific experiments conducted in deep sea basins often require the simultaneous Eulerian acquisition of large scale (kilometers) and small scale (meters) measurements. To cover a large frequency band, these measurements must be made over extended periods of time (months). To minimize noise to signal ratios, particularly when dealing with small scale measurements, sensor motion must be as small as possible.

A practical way, perhaps the only way, to make such measurements is to attach oceanographic sensors at various locations on a large, stable, multileg cable structure.

To be cost-effective such a structure should be implanted for a relatively long period. The use of recently developed mooring line materials and power sources for underwater applications should permit a life expectancy of five years.

Several large cable arrays have been deployed in the last decade or so. Project Seaspider[1] was an early effort in which a large trimoor structure was successfully deployed on the Blake Plateau. This project pioneered the use of neutrally buoyant legs. Another trimoor, the Pacific Seaspider[2] was an ambitious undertaking which developed problems during deployment caused from rotation of a leg. Skop[3] made significant improvements in the analytical methods used to design and predict the behavior of such arrays. A large linear array was deployed off Bermuda by the C. S. Draper Labs[4]. The Woods Hole Oceanographic Institution[6-7] successfully deployed and recovered a large trimoor in 5400 meters water depth. Project Linear Chair[8] and the MABS system[9] pioneered the use of Kevlar cable structures in arrays.

The installation of more complex structures is now feasible. The pioneering work over the past decade or so makes practical deployment schemes not considered possible in the past. We now have precise surface, subsurface and bottom navigation capabilities which can be interfaced with a computer and a visual display unit. Both manned and unmanned submersibles are available to do many tasks associated with an array deployment, such as instrument and sensor attachments, electrical connections and data readout of instruments.

Lastly, new materials such as Kevlar, provide mooring materials which are non-corrosible and weigh only one-seventh the weight of a comparable steel cable in water.

2.0 ARRAY REQUIREMENTS

The desirable features of a cable structure deployed in the deep ocean for the purpose of long term oceanographic measurments are hereafter described.

Geographical Location

For the purpose of this report the cable array is to be deployed in a flat bottom oceanic basin with a typical depth of 5000 to 6000 meters and away from major currents such as the Gulf Stream. Obviously specific scientific objectives and priorities will, in the long run determine where the cable array should be implanted.

Life

To be cost effective on one hand and to allow measurements to be made over periods of several years on the other hand, the cable array should have a reasonably long life expectancy. Based on the state-of-the-art a cable structure with a service life of five years appears quite feasible.

Size

The simultaneous measurements of oceanographic parameters from sensors placed several kilometers apart is of considerable interest to the scientific community. Examples of studies which can be performed using this technique are:

- o Study of internal waves
- o Bottom transport
- o Mixing processes
- o Flux measurements
- o Acoustic studies
- o Fine scale tomography
- o Experiments in geophysics

In the vertical, the maximum dimension of the array is set by the water depth, typically 5000 meters. The maximum horizontal distance between two points on the array obviously depends on the array geometry. For the candidate configurations hereafter considered this maximum dimension varies from 5000 meters to 20,000 meters.

Versatility

By versatility we mean that the array should be able to accomodate, simultaneously or sequentially, a variety of scientific experiments. Means for achieving this goal include:

- o Capability for small (meters) and large (kilometers) vertical and horizontal scaling.
- o Flexibility in data acquisition modes. The array should be capable of supporting self recording instruments as well as remotely powered sensors.
- o Flexibility of data retrieval methods. The array should be capable of providing real time data transmission and/or permit easy data recovery on a periodic basis.

Stability

As previously mentioned, reducing sensor motion to a minimum greatly benefits the quality of the data acquired from the array. Good stability is achieved if the geometry of the array does not change appreciably when the array is subjected to varying oceanic currents.

Symmetry

A symmetrical geometry increases the usefulness of any array. Symmetry can be used to advantage to duplicate scaling at different depths and to easily monitor the three Cartesian components of certain parameters observed. The response of symmetrical arrays is less dependent on current direction an important consideration when deploying arrays in areas where rotating currents are likely to occur.

Ease of Deployment

Ease of deployment and practicality of servicing will be one of the most attractive features of any candidate configurations. To be practical and safe the deployment scenario should make use of modern proven techniques such as

- o Bottom mounted transponder network for precise acoustic navigation.
- o Special ship propulsion and controls.
- o Special deck machinery.
- o Use of manned or unmanned underwater vehicles.

Servicing

Replacement of power packs, collection of data records, replacement of sensors should be scheduled on a routine basis, say every six months or once a year. Servicing should not require retrieval of the main array components which shall remain installed for five years of active life.

Special Features

Additional features of interest which have been mentioned in the scientific community include:

- o Capability of making stable measurements close to the surface.
- o Directionality obtained by designing the array somewhat like a large stable antenna.
- o Possibility of using two stable arrays separated by several hundred kilometers.

3.0 CANDIDATE CONFIGURATIONS

To initiate the feasibility study a number of array configurations which could meet the requirements just reviewed were first established. Their relative merit and capabilities was then qualitatively assessed.

Those worthy of further investigation were then incorporated into a more rigorous comparative stability and structural analysis.

The candidate configurations can be classfied in the following categories:

- o Planar Arrays
- o Biplanar Arrays
- o Truncated Pyramids
- o Cross Arrays
- o Prismatic Arrays.

3.1 DESCRIPTION

Each of the categories mentioned above is hereafter described and depicted in the accompanying figures.

Planar Arrays

The simplest array consists of two or more buoys moored in a single plane and possibly connected to each other by horizontal mooring lines. The horizontal legs are neutrally buoyant (or nearly so) and provide sensor attachment points. This configuration (see Figure 1) has intrinsic poor stability both in the normal and the longitudinal direction. The planar array can be made any length in principle at least. Its spatial sampling capability is limited to a single plane.

Biplanar Arrays

The next simplest and more stable configuration would be the biplanar array shown in Figure 2. This array permits measurements to be made in two inclined planes.

Truncated Pyramids

As the name implies a truncated pyramid array is obtained by cutting a regular pyramind with an horizontal plane located say, 500 meters below the surface. An example of such array configuration would be the square truncated pyramid array shown in Figure 3. By connecting the four Apex buoys to an anchor located at the center of the pyramid base, the inverted pyramid array shown in Figure 4 is obtained.

Cross Arrays

A cross array is made of two planar arrays crossing each other at right angles. The simplest cross array would be the five buoy array shown in Figure 5. For improved stability the end buoys are moored on two legs extending outward from the array.

Prismatic Arrays

Interesting array configurations can be obtained by using variations of geometric prisms. Only two of the numerous possibilities have been retained for presentation: the hexaprism and the octahedron. The

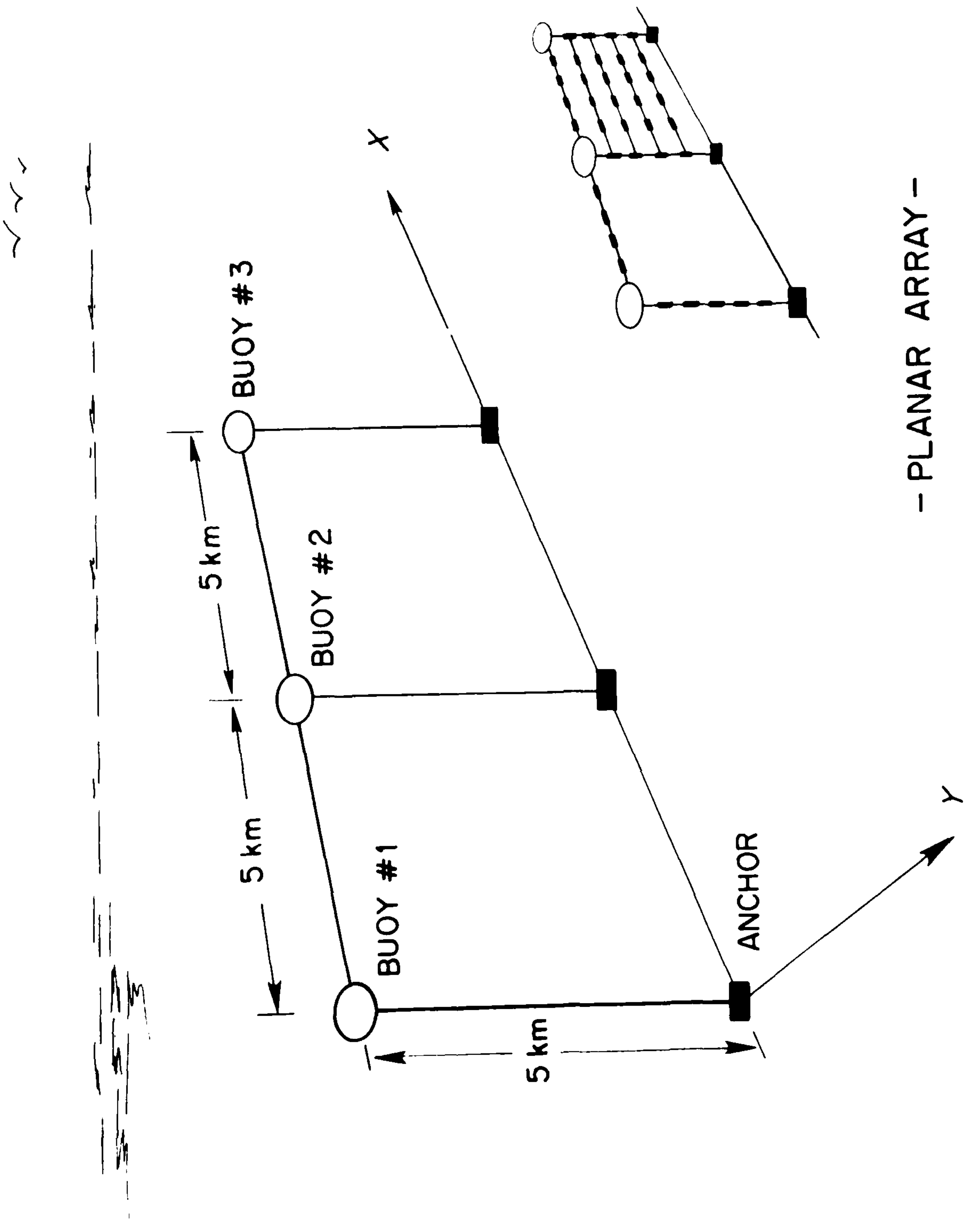
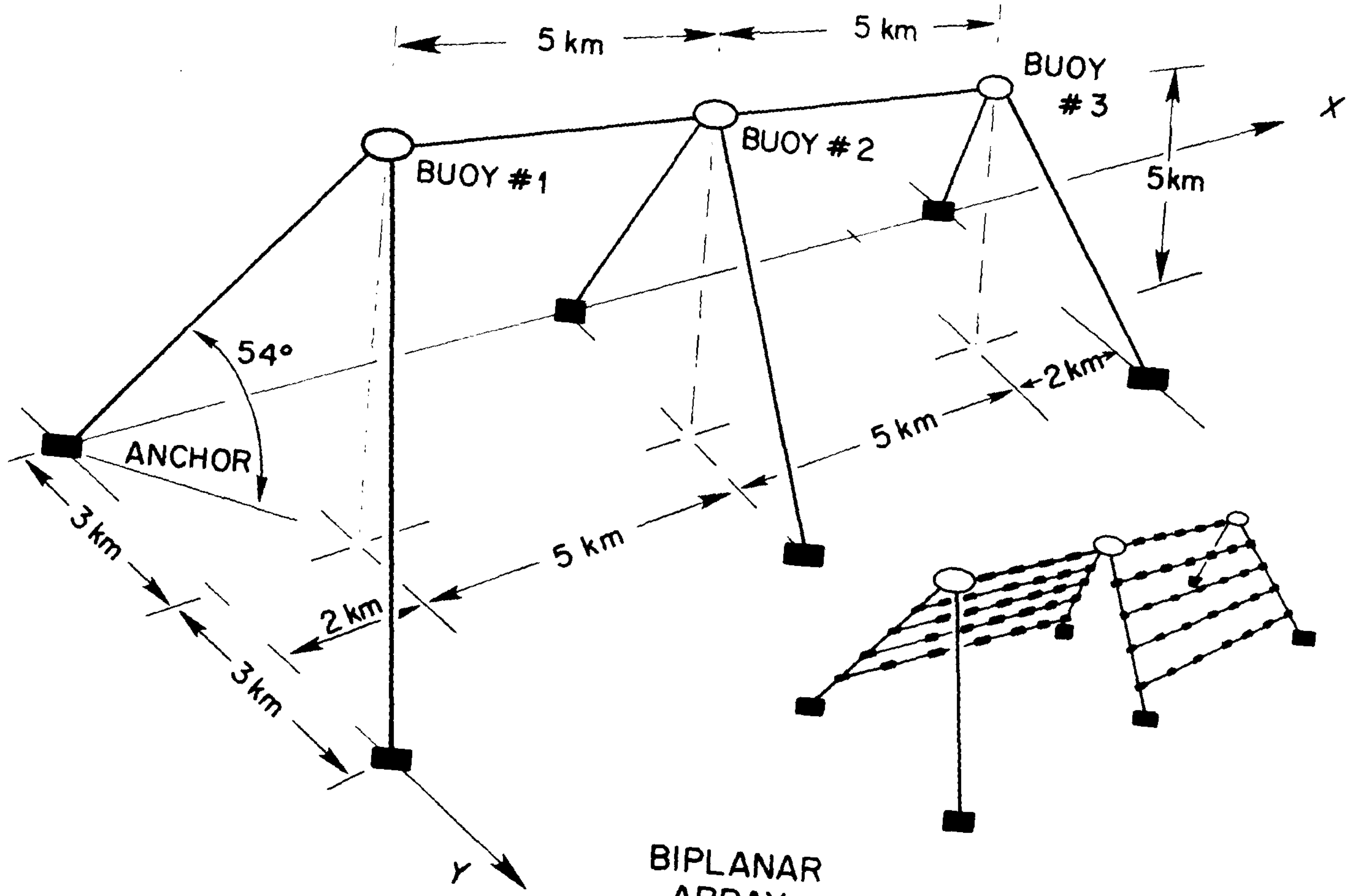


Figure 1



BIPLANAR
ARRAY

Figure 2

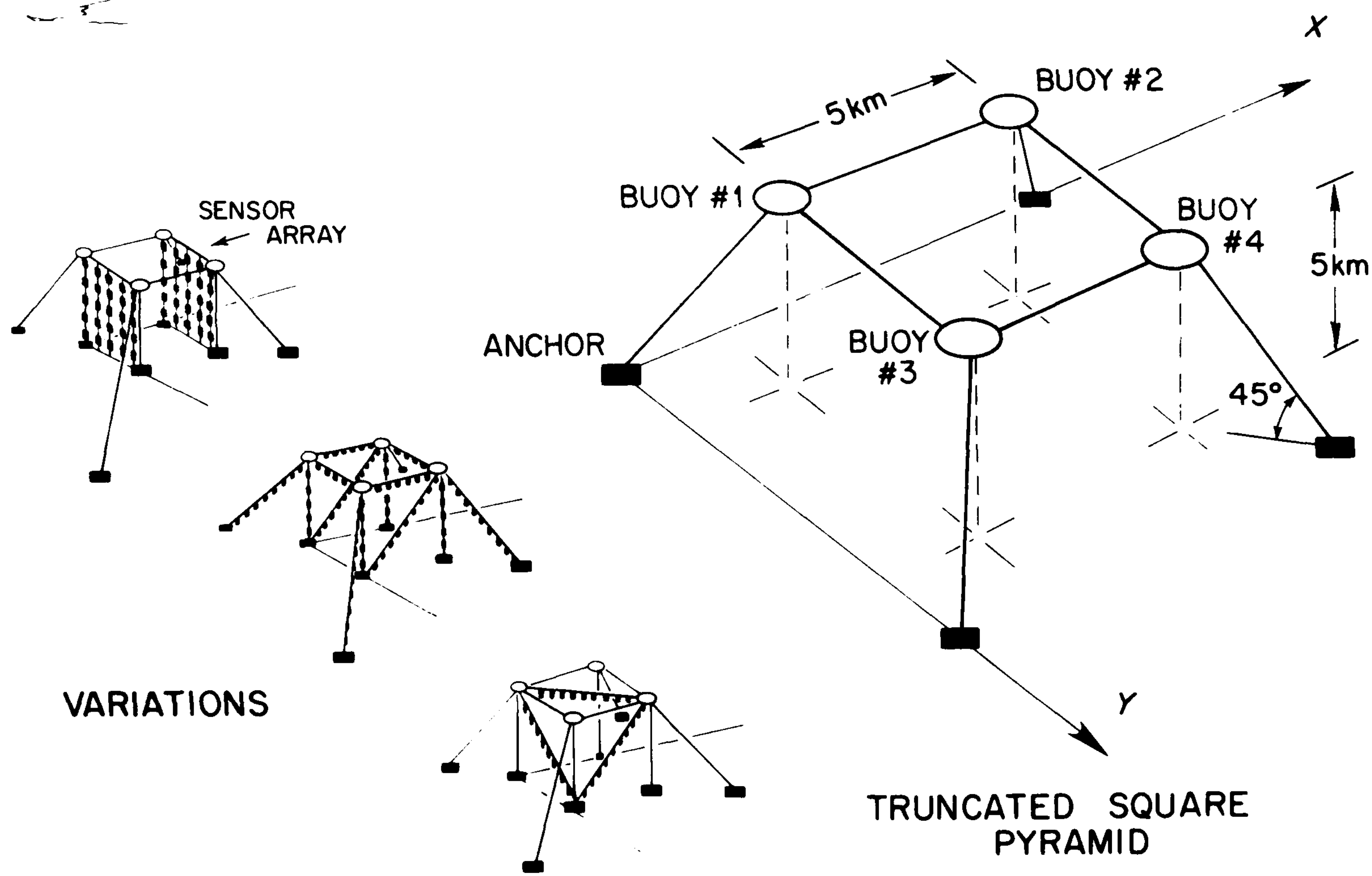

X
BUOY #2
5km
BUOY #1
SENSOR
ARRAY
BUOY
#4
5km
ANCHOR
BUOY
#3
45°
Y
VARIATIONS
TRUNCATED SQUARE
PYRAMID

Figure 3

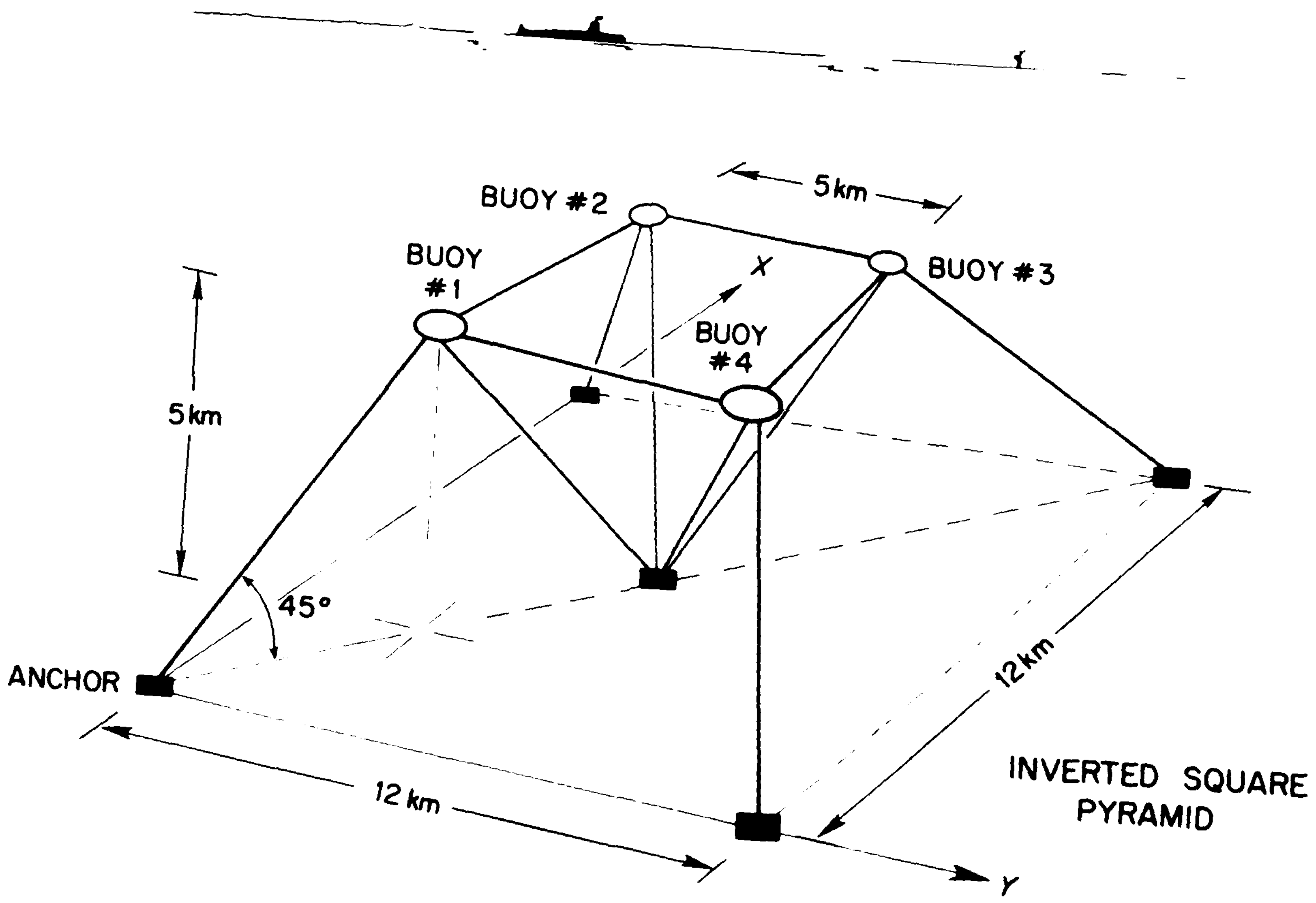

BUOY #2
5km
BUOY #1
X
BUOY #3
BUOY #4
5km
45°
ANCHOR
12 km
12 km
INVERTED SQUARE PYRAMID
Y

Figure 4

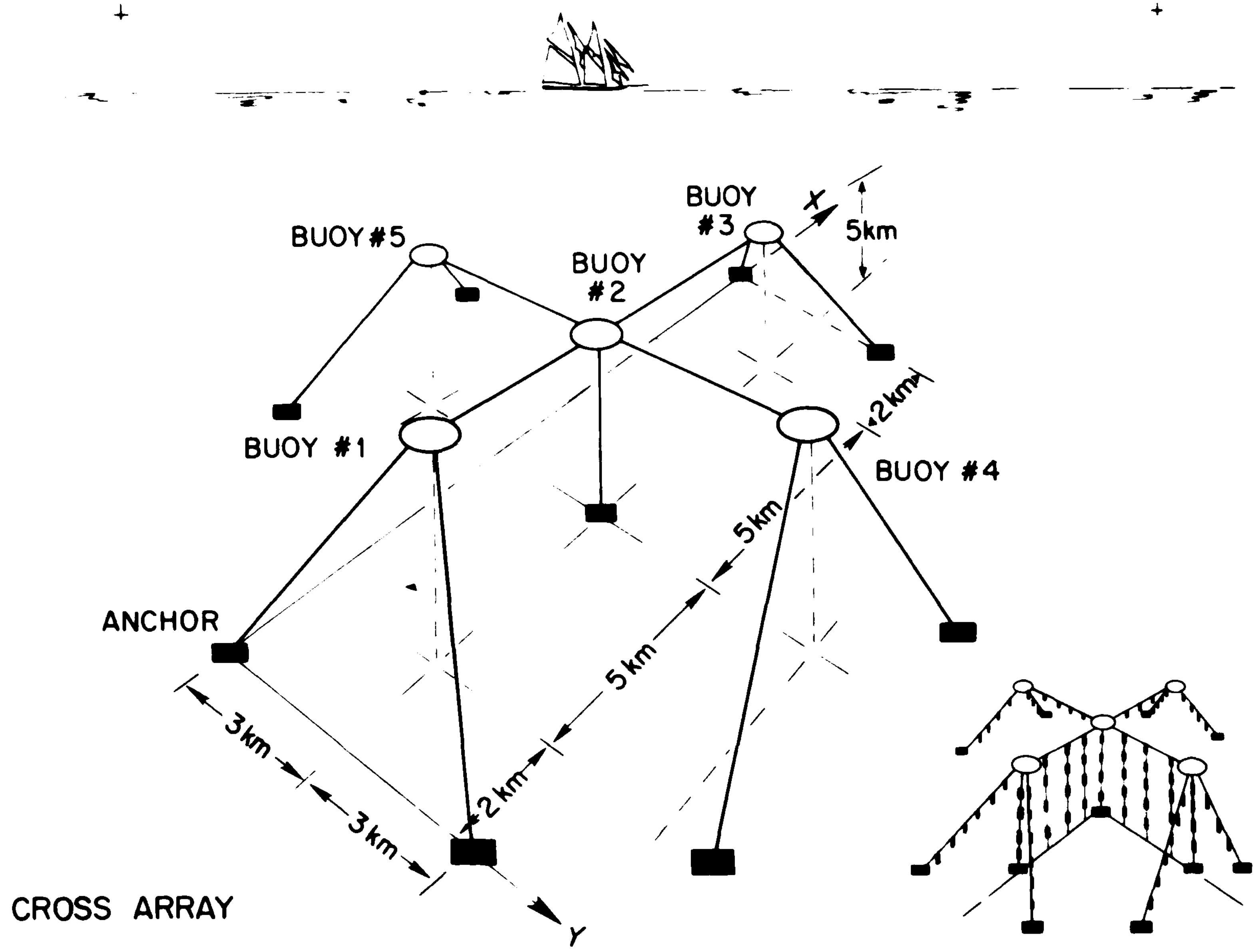

BUOY #5
BUOY #2
BUOY #3
X
5km
BUOY #1
BUOY #4
2km
5km
5km
2km
ANCHOR
3km
3km
Y
CROSS ARRAY

Figure 5

hexaprism (Figure 6) is interesting because of its stability and symmetry between opposite faces. It provides for large spatial scaling. The octahedron (Figure 7) is the most ambitious array included in the report. Possible sensor arrangements using the hexaprism and other configurations are suggested on the figures.

3.2 ADVANTAGES AND DISADVANTAGES

Each array type has different characteristics such as the number of floats, anchors,etc. The spatial sampling scales possible with each vary markedly. Certain of the arrays are easier to deploy and service than others. Advantages for one application may be a disadvantage for another. In general, the cost will be proportional to the number of elements in the array. Advantages and drawbacks specific to the array configurations previously described are hereafter briefly reviewed.

Planar

The planar array is the simplest and the easiest to install. Because of its open construction it can be easily inspected and serviced by a submersible. It can however sample only in one plane. Its stability as further evidenced in the analytical comparative study presented in Section 4, is extremely poor.

Biplanar

The poor stability of planar arrays can be improved by mooring the array buoys with two legs rather than one. For added stability the end buoys can be angled out. The tent configuration thus obtained can still be easily implanted and serviced. Because of its geometry its sampling capacity is not uniform in all directions. A combination of several tents may be of particular interest to the scientific community.

Truncated Pyramids

The "horizontal" cables connecting the apex buoys of truncated pyramid arrays permit small and large spatial scaling in the horizontal plan containing the apex buoys. The mooring legs provide for variable horizontal spacing of sensors as a function of depth. A large selection of horizontal and vertical sensor spacing is possible with the inverted pyramid array.

The symmetry obtained from pyramid geometry is used to advantage to permit orthogonal measurements to be made. Furthermore the magnitude of current induced buoy displacements is no longer, in this class of arrays, strongly dependent on current direction.

Because of its complexity the inverted pyramid array is difficult to deploy and servicing by submersible may not be feasible.

Cross Arrays

Here again sensors placed on the horizontal cables connecting the five apex buoys of a cross array can make small scale as well as large

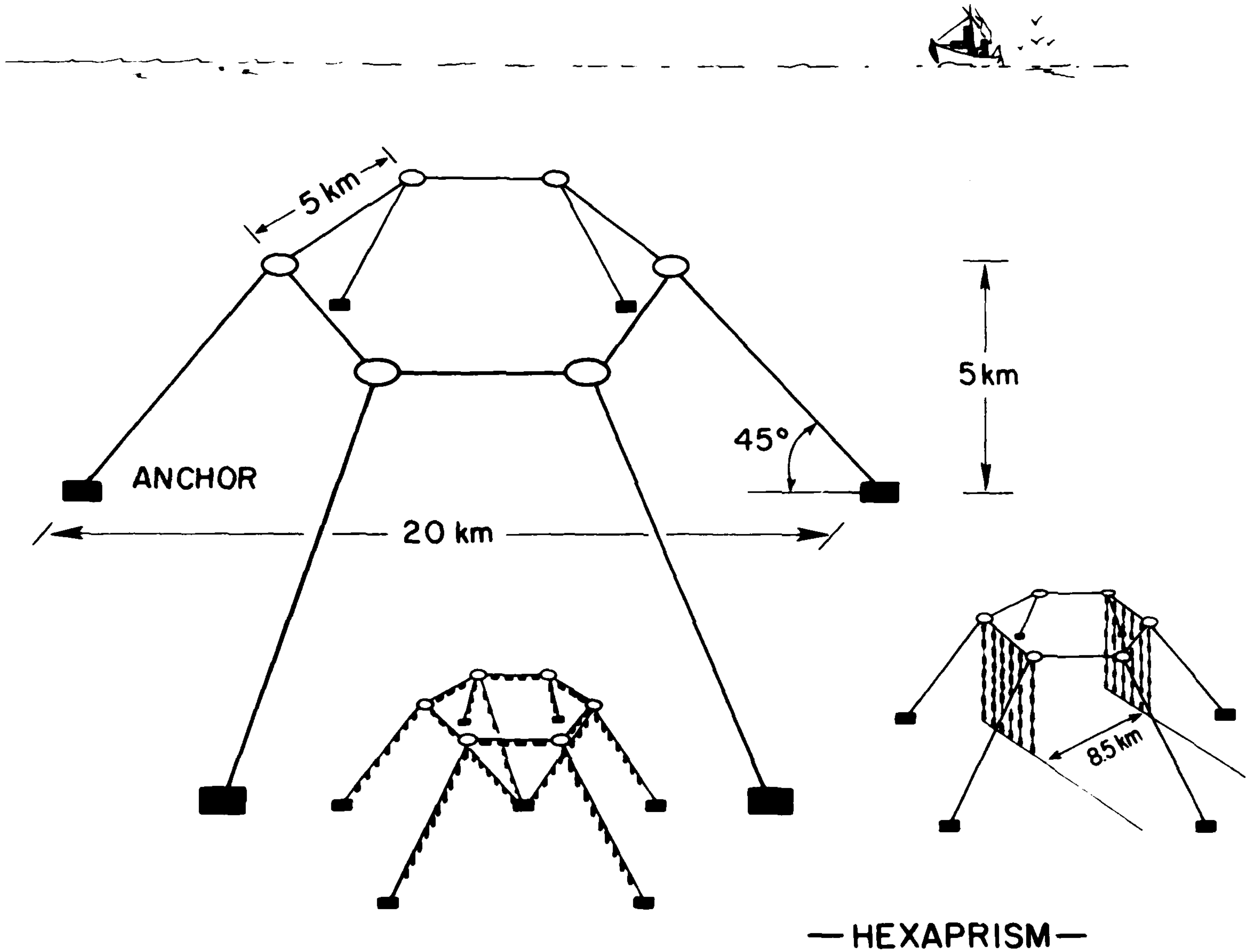


Figure 6

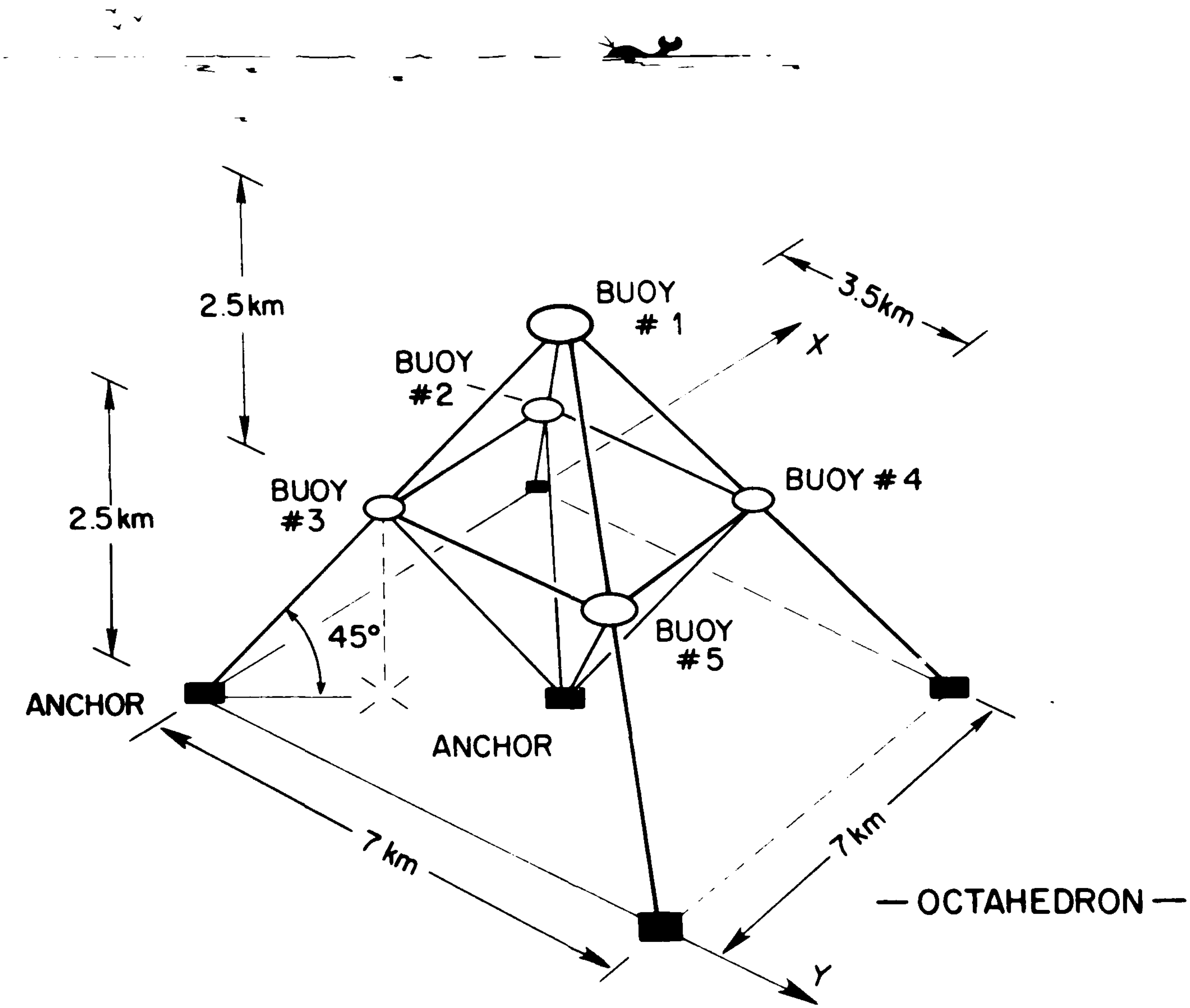

2.5km
2.5km
3.5km
BUOY
1
BUOY
#2
BUOY
#3
BUOY # 4
BUOY
#5
X
Y
45°
ANCHOR
ANCHOR
7 km
7 km
— OCTAHEDRON —

Figure 7

scale orthogonal measurements in the plane of the buoys. Mooring legs provide additional sensor placement possibilities. The large dimension and the symmetry of cross arrays make these arrays very versatile. Their implantation should not be difficult but will require a great deal of planning and sea time. They can be serviced well by submersibles.

Prismatic Arrays

As mentioned earlier, the prismatic arrays can combine the best and the worst of both worlds. On one hand they provide for a great deal of scientific versatility offering, particularly the octahedron configuration, a large choice of horizontal and vertical sensor spacing. On the other hand they require a large number of components, and/or are extremely difficult to install. These two factors certainly would reflect on their cost. For these reasons these arrays do not appear to be practical nor feasible and they have not been retained for further consideration.

A detailed analysis of several versions of all other array configurations follows.

4.0 COMPARATIVE STABILITY AND STRUCTURAL ANALYSIS

4.1 METHOD OF ANALYSIS

The Fortran program DESADE was used to compute the geometry, the stresses, and the current induced displacements of a number of structural cable arrays. This program was written by R. A. Skop[10] and J. Mark of the Naval Research Laboratory, Washington, D.C. (1973).

To gain familiarity with the program capabilities and limitations, cable arrays of simple geometry were first considered. These basic arrays included:

- Single point moored
- Bimoor
- Trimoor
- 4 leg mooring
- Planar C (2 buoys)
- Planar E (3 buoys)
- Planar EX (3 buoys)

It was felt that considerable insight would be gained by first studying arrays of simple geometry. Such a study would reveal trends useful for the better understanding of more complex arrays. Results of this preliminary and indeed enlightening study are reviewed in Section 4.4 "Case Studies".

More complex arrays, some of them designed to take advantage of the good features apparent from this preliminary study, were then analyzed, again with the help of DESADE. These medium complexity arrays included:

- o Biplanar "Tent"
- o Biplanar "Supertent"
- o Truncated Trimoor
- o Truncated Square Pyramid
- o Cross Array I
- o Cross Array II

The inverted square pyramid array shown in Figure 4 has interesting features. It could be quite stable and versatile. Its complexity and particular geometry made its analysis difficult. Computer runs with different values of cable lengths, weight, and elasticity were made but none of them could converge within the accuracy prescribed for the previous configurations. Given the cost of these runs, the scope of this report, and the practical difficulty of deploying such an array, no further attempts were made at obtaining a convergent run.

The analysis essentially consisted in subjecting the arrays to the same current profile and obtaining the displacements from the no current equilibrium condition. The current profile was applied first in the direction of the "X" axis, and then at various angles from the "X" axis thus establishing the "worst current" condition. Array responses to these currents were established for various degrees of cable elasticity.

4.2 CURRENT PROFILES

The deep ocean basins of the world can generally be characterized as having flat topographical features; the water depth is 5000 to 6000 meters deep and current features are generally baroclinic in nature. It has been observed in many ocean basins that occasional large-scale intrusions of water masses in the form of large eddies occur. The velocities associated with these eddies can be high and sometimes have a large vertical scale.

For purposes of design and to quantify the array motions resulting from currents, two current profiles were used and are shown in Figure 8. The profile of current vs depth called "operational" is that current which persists most of the time. The second, the "survival" profile is double the operational and is used to determine the maximum stresses and deflections of an array. Current direction in both cases is considered planar.

4.3 MAIN COMPONENTS OF CANDIDATE ARRAYS

For the purpose of this comparative analysis the number of array components was kept to the minimun required by the array geometry. All buoys were assumed to be spherical. All cables were assumed to have the same diameter (0.65 inches) and the same immersed weight (-0.05 lb/foot). No discrete devices (buoyancy elements, instruments, etc....) were to be incorporated in the array analysis. To permit a certain degree of stability comparison between arrays, the buoyancy of the buoys was adjusted to yield approximately the same buoyancy to cable weight ratio for the different arrays to be compared. Buoyancy thus used ranged from a low value of

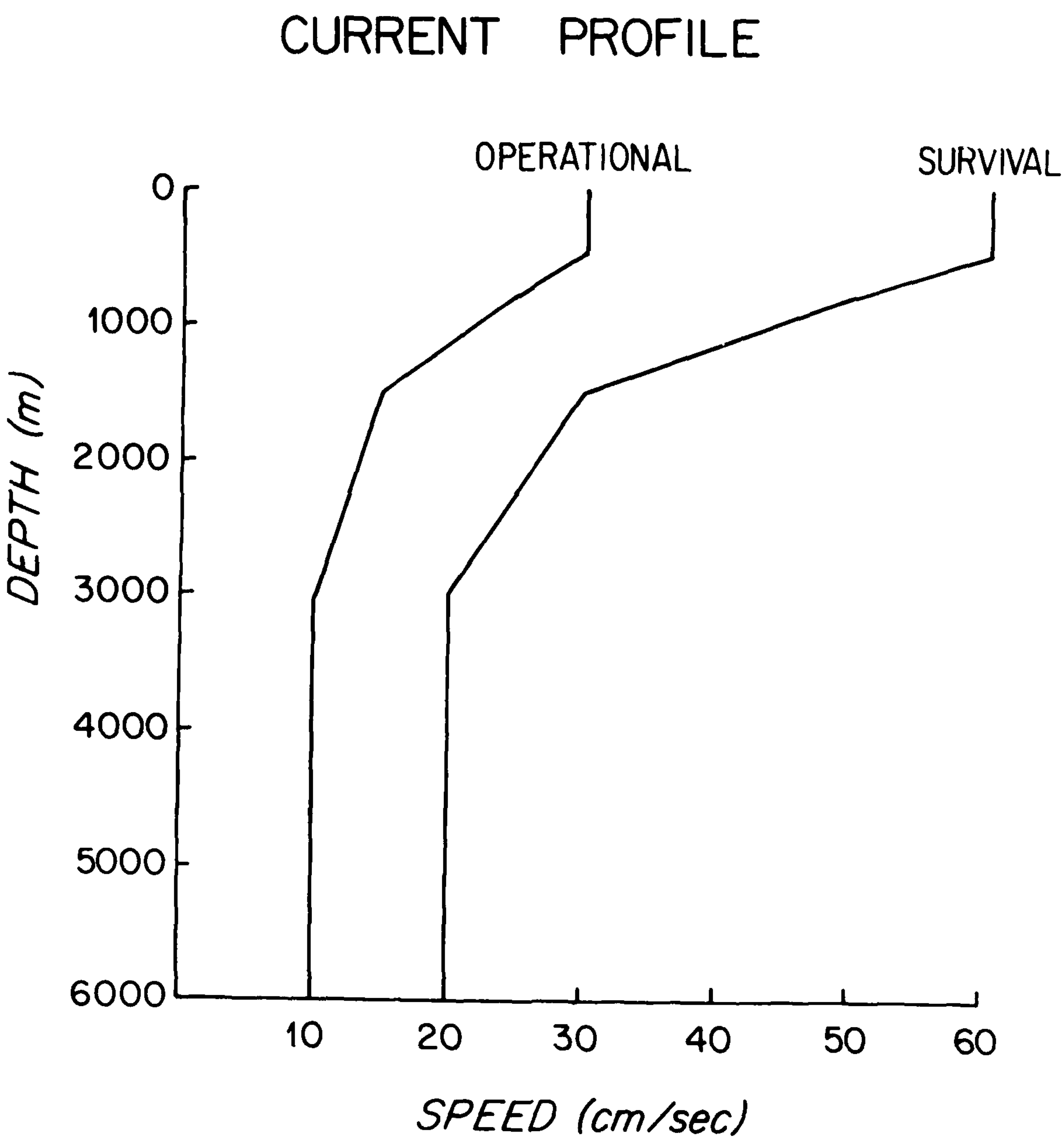

CURRENT PROFILE
OPERATIONAL
SURVIVAL
0
1000
2000
3000
4000
5000
6000
DEPTH (m)
10
20
30
40
50
60
SPEED (cm/sec)

Figure 8

5000 lbs to a high value of 20,000 lbs. To enhance the comparison arrays were analyzed either as rigid (no cable elasticity at all) or as very compliant (modulus of elasticity of cable $E = 5x10^5$ which would be typical of nylon. All runs were performed with the "operational" current profile. Results from these runs are hereafter reviewed.

4.4 CASE STUDIES

SINGLE POINT MOOR

Single point moors (Figure 9) have the advantages of simplicity and low cost. They can be designed to undergo relatively small displacements. Several single point moors can be, and often have been, combined to form oceanic arrays of large horizontal scaling. Current induced displacements of a 5000 lbs and a 10,000 lb buoy moored with a rigid first, then a compliant five kilometers long mooring line were computed. Results are as tabulated below.

SINGLE POINT MOOR

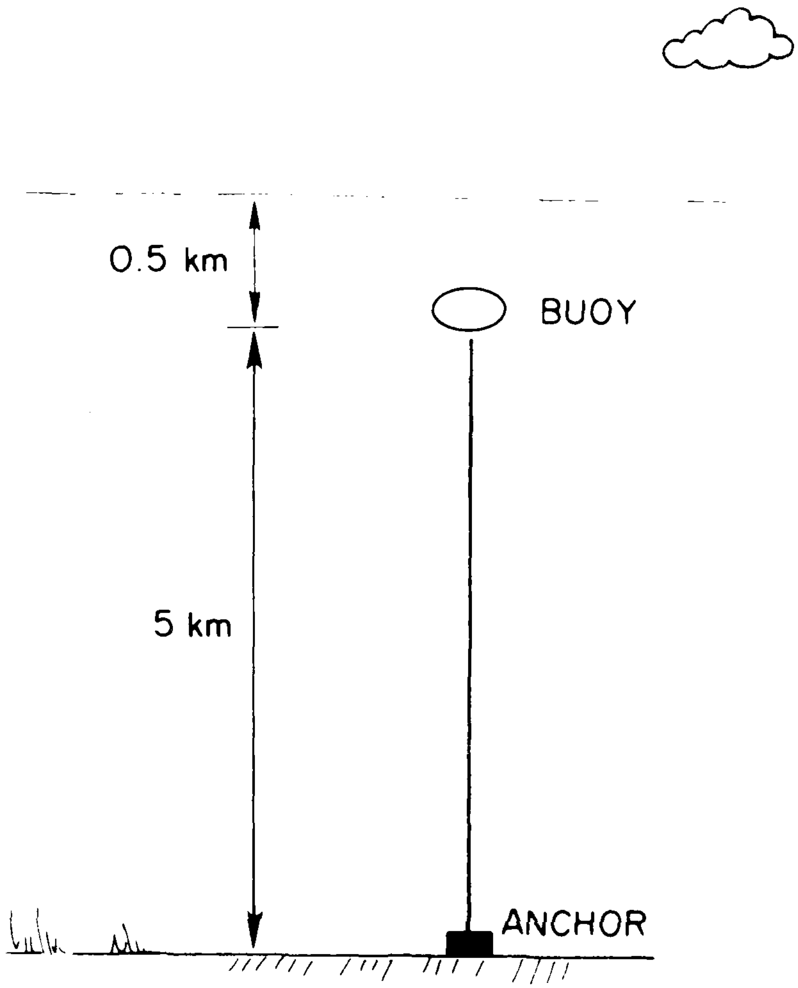
Modulus of Elasticity (psi)	Buoyancy of Buoy (lbs)	X Disp (meters)	Z Disp (meters)	TOTAL Disp (meters)
$E = \infty$	5000	205.43	-4.88	205.49
$E = 5x10^5$	5000	237.73	-6.10	237.82
$E = \infty$	10000	99.97	-1.1	99.98
$E = 5x10^5$	10000	134.38	-1.83	134.39

These values provide a basis for comparing the displacement of other arrays.

BIMOOR

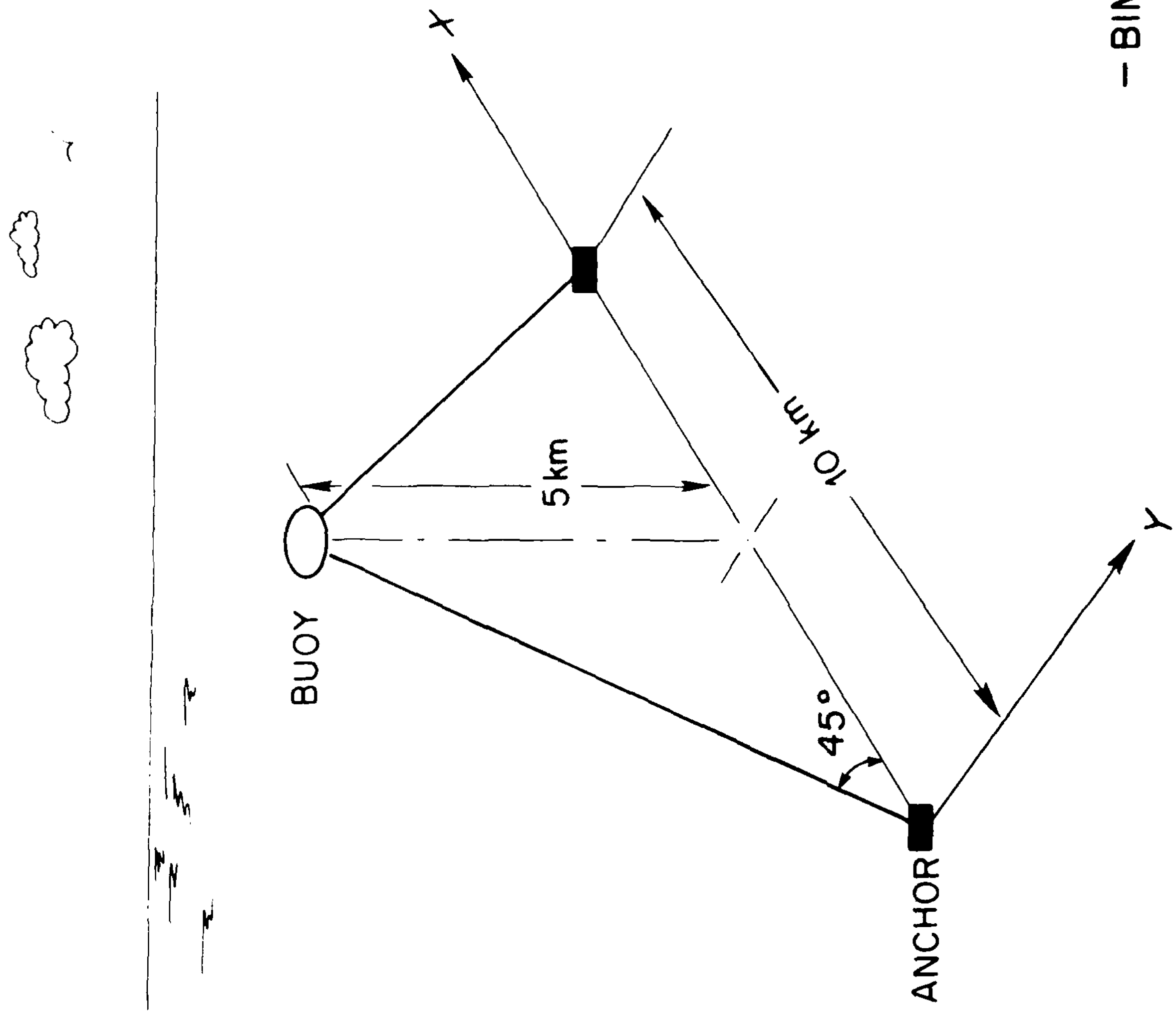
The next simplest array is one having one buoy and two mooring lines, as shown in Figure 10. When compared to a single moored buoy, one would expect the motion of a bimoor buoy to be considerably less when the current flows in the plane of the bimoor and as large or larger when the current flows normal to that plane.

To quantify this assertion computations were made of the displacements of two bimoors, one with a 5000 lb buoy and one with a 10,000 lb buoy. The results are hereafter tabulated.



—SINGLE POINT MOORED—

Figure 9



— BIMOOR —

Figure 10

BIMOOR I (5000 lbs Buoyancy)

Modulus of Elasticity (psi)	Current Angle from X axis* (degrees)	X Disp (meters)	Y Disp (meters)	Z Disp (meters)	TOTAL Disp (meters)
$5x10^5$	0	3.66			3.66
	15	3.35	150.26	-2.44	150.28
	30	3.35	303.87	-10.06	304.18
	45	3.05	452.61	-22.25	453.22
	60	2.13	579.70	-36.57	580.62
	75	1.52	664.43	-48.77	665.96
	90		694.0	-53.34	695.82

Average = 407.7 m

* The X axis is assumed to be in the plane of the bimoor.

BIMOOR II (10,000 lbs Buoyancy)

Modulus of Elasticity (psi)	Current Angle from X axis (degrees)	X Disp (meters)	Y Disp (meters)	Z Disp (meters)	TOTAL Disp (meters)
E = ∞	0	10.06			10.06
	15	10.27	79.85	-1.0	80.46
	30	9.94	162.45	-3.05	162.76
	45	8.53	245.96	-6.10	246.27
	60	6.40	319.41	-10.36	319.72
	75	3.66	370.01	-14.02	370.31
	80		388.6	-15.54	388.91

Average = 225.5m

The conclusions that can be drawn from these results are:

- The bimoor array performs better than the single point moor as long as the current flows within 20 degrees or so from the plane of the undisturbed bimoor. Thereafter as the current becomes more and more normal to that plane the buoy keeps on moving downstream, sinking further and further. With the current at 90° from the X axis, the 5000 lb buoy of a compliant bimoor has sunk to a depth nine times greater than the depth of a similar single point moored buoy and has experienced a total displacement three times as big. Adding a second leg is clearly detrimental unless the current is more or less flowing in the plane of the two legs.

- Doubling the buoyancy considerably reduces the dip and displacement of the compliant bimoor. With 10,000 lbs buoyancy the maximum dip and total displacement of the buoy are 3.4 and 1.8 times smaller.

- Increasing the rigidity, or stiffness of the mooring legs has a lesser effect on the bimoor stability. It can be seen from the results that the maximum displacement of a 10,000 lb rigid bimoor (277.05 m) is only 29% less than the maximum displacement of the compliant one (388.91 m).

TRIMOOR

The trimoor (Figure 11)is still a relatively simple buoy system with one buoy and three equally spaced anchoring lines, was considered next. By using three legs instead of two one would expect the apex displacement to be much less dependent on current direction.

To again quantify this motion two identical trimoors with buoyancy of 5000 and 10,000 lbs respectively were subjected to the operational current profile. The current angle of attack was increased by steps of 15 degrees from 0 to 90 degrees thus covering all possible non-repetitive mooring responses (Figure 12). Based on preceding studies (Reference 7), the angle between the mooring legs and the horizontal sea floor was chosen to be 54 degrees. The two cases were analyzed assuming the mooring legs to be compliant ($E = 5x10^5$). Results of these runs are hereafter tabulated.

TRIMOOR I - (5000 lbs Buoyancy)

Current Angle from X axis (degrees)	X Disp (meters)	Y Disp (meters)	Z Disp (meters)	TOTAL Disp (meters)
0	72.23	-4.57	-11.28	73.15
15	65.63	15.24	- 9.14	67.66
30	56.69	33.22	- 8.23	66.14
45	45.72	40.84	- 9.14	61.87
60	32.61	64.92	-11.89	73.45
75	17.37	76.50	-14.32	79.55
90	-	81.07	-15.54	82.29

Average = 72.01 m

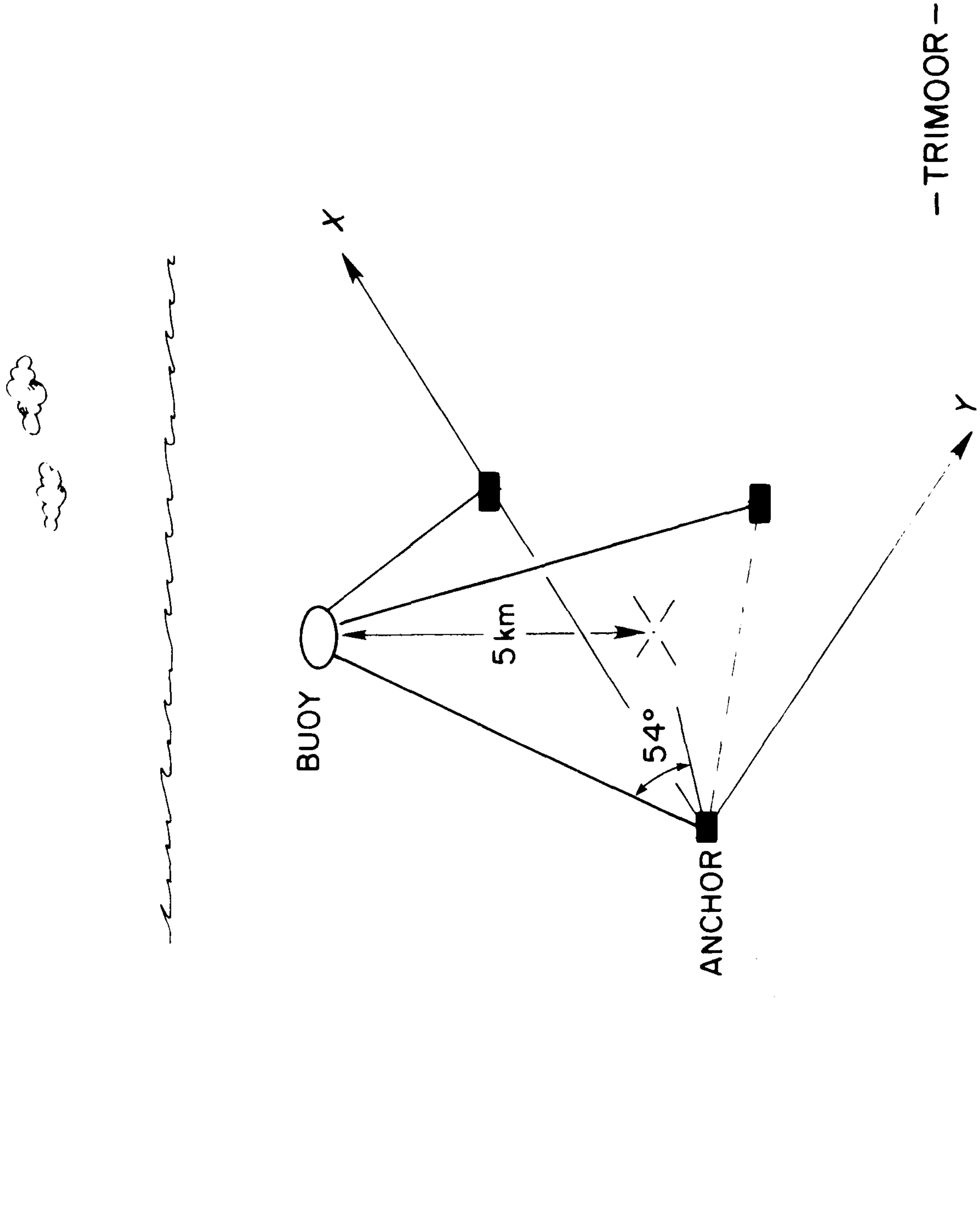


Figure 11

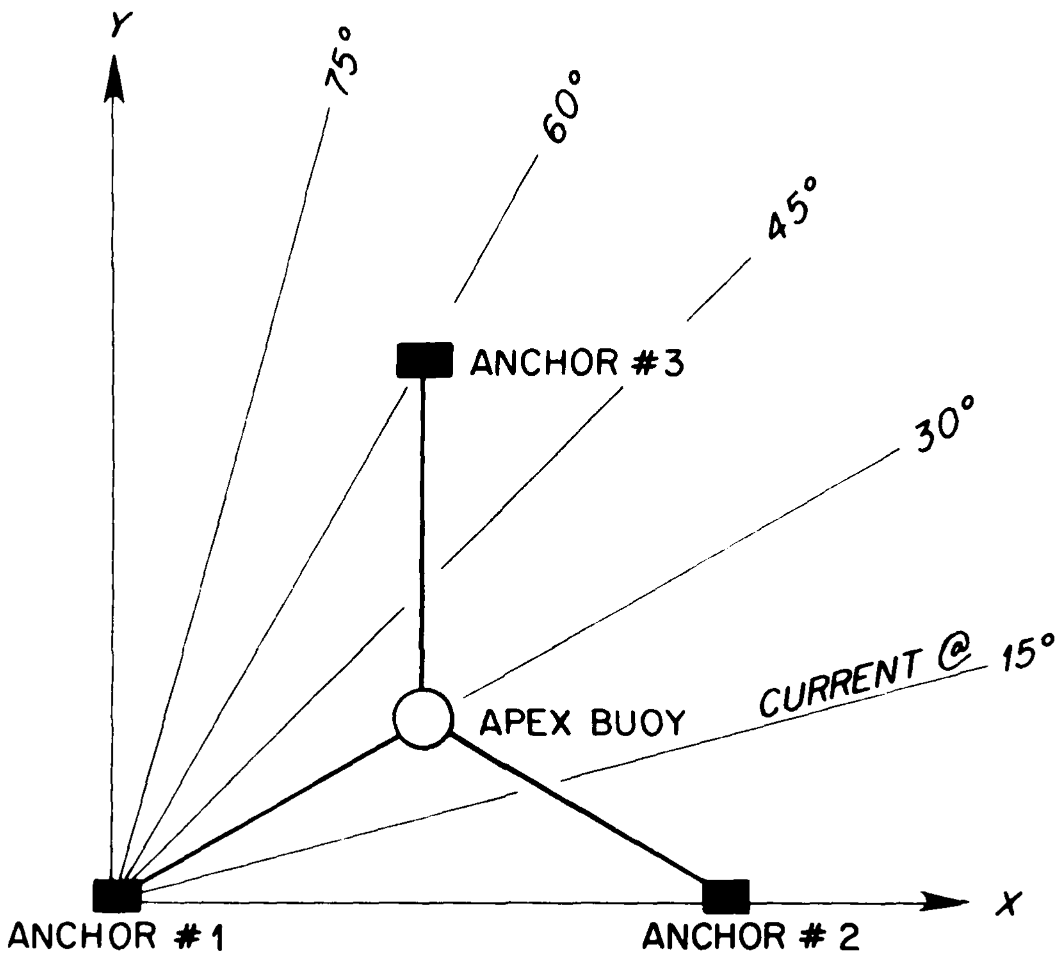


DIAGRAM SHOWING THE CURRENT
ANGLES USED IN THE TRIMOOR ANALYSIS

Figure 12

TRIMOOR II - (10,000 lbs Buoyancy)
($E = 5x10^5$ psi)

Current Angle from X axis (degrees)	X Disp (meters)	Y Disp (meters)	Z Disp (meters)	TOTAL Disp (meters)
0	38.1	1.0	-1.0	38.15
15	36.88	11.28	- .61	38.56
30	33.53	20.12	- .61	39.10
45	27.74	27.43	- .61	39.01
60	20.12	32.92	-1.22	38.71
75	10.67	36.27	-1.52	37.79
90	-	37.18	-1.52	37.18

Average = 38.36 m

These interesting results show the following:

- The trimoor is remarkably more stable than the single point moor or the bimoor. The average displacement of the 5000 lbs trimoor is found to be 72.01 meters, as compared to 237.82 meters for the single point moor and 222.5 meters for the bimoor.

- To a first approximation at least, the total displacement of the trimoor apex is indeed independent of the current direction. This fact is emphasized by the polar diagram shown in Figure 13 which gives the total displacement of the 10,000 lb bimoor and of the 10,000 lb trimoor as a function of current direction.

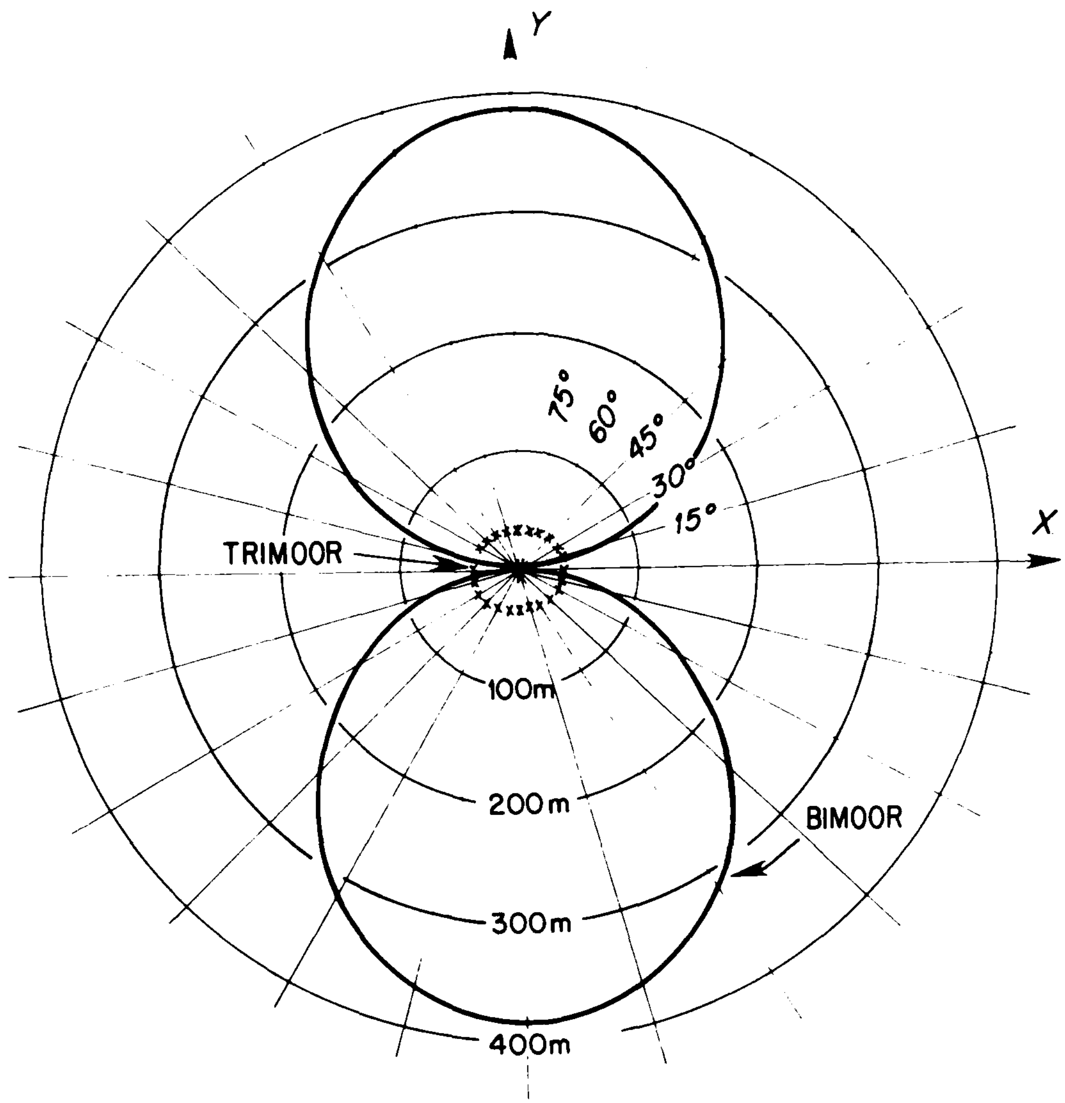
- As evidenced by the results obtained for the 5000 lb case, the worst current case is obtained with the current at 90 degrees from the X axis. In this particular instance two legs of the mooring are upstream whereas the third one is downstream and entirely in the direction of the current. The minimum displacement is achieved at a current angle of 45 degrees. Minimum dip, however, is obtained with the current at 30 degrees from the X axis.

- Increasing the buoyancy of the apex buoy to 10,000 lbs reduces the average displacement of the trimoor apex to almost one-half its value with the 5000 lb buoy.

The good features revealed by this rather succinct trimoor analysis were later incorporated in the "supertent" and the truncated trimoor array configurations.

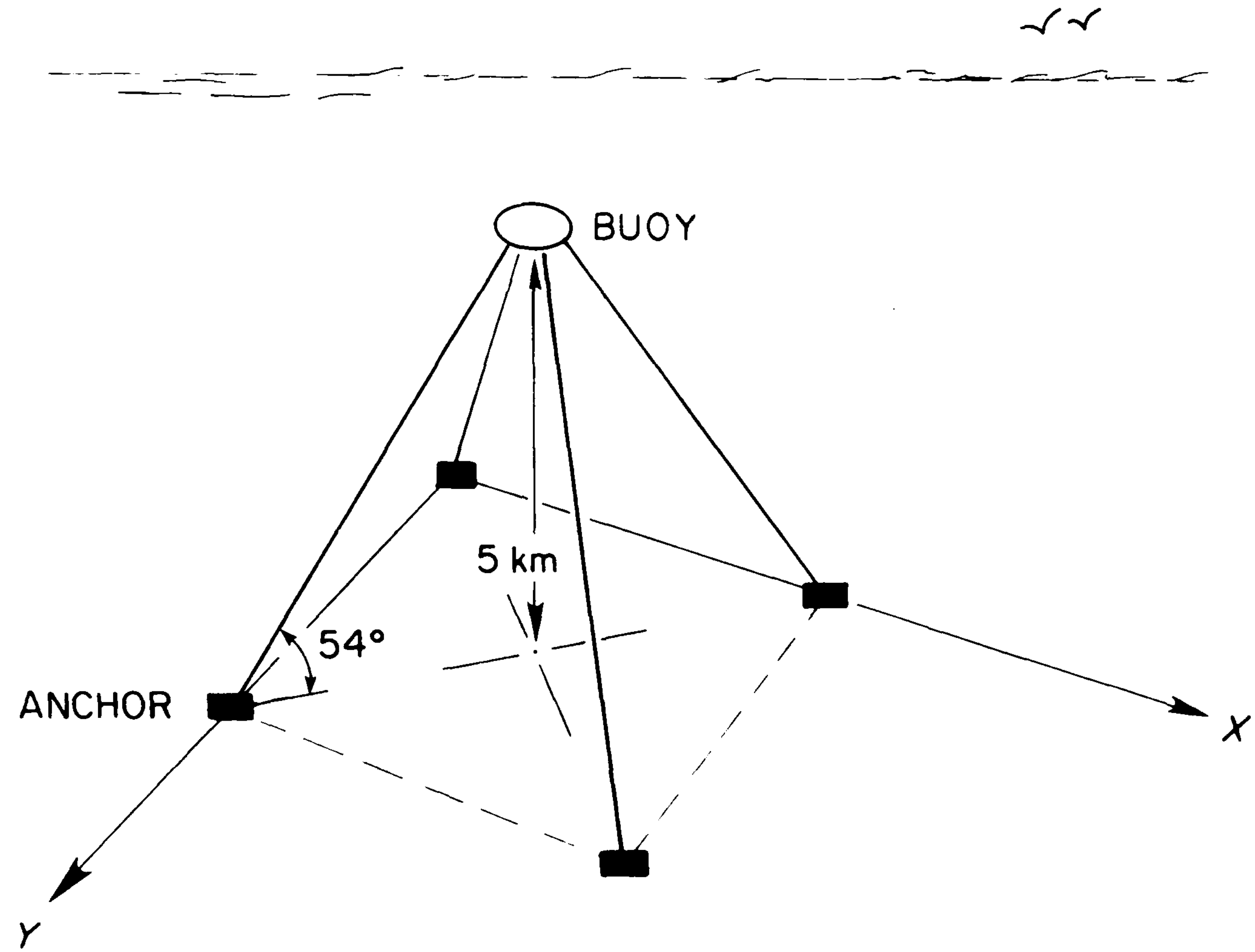
<u>4 LEG MOORING</u> (Figure 14)

To investigate the gain in stability which could be obtained by adding one more anchoring line, a 4 leg mooring with a buoyancy of 20,000 lbs was analyzed. The mooring legs were compliant and made a 54 degree angle with the sea floor. Current directions considered were at zero



POLAR DIAGRAM OF BIMOOR AND TRIMOOR DISPLACEMENT (m)

Figure 13



— FOUR LEGGED MOORING —

Figure 14

and 45 degrees from the X axis. Computation results are as shown hereafter.

4 LEG MOORING
(E = 5×10^5 psi)

Current Angle from X axis (degrees)	X Disp (meters)	Y Disp (meters)	X Disp (meters)	TOTAL Disp (meters)
0	41.15		-.33	41.15
45	28.95	28.95	-.36	41.75

These results indicate that despite a considerable increase in buoyancy of the apex buoy, the displacement remains essentially the same as the one experienced by the 10,000 lb buoy of the compliant trimoor. On the other hand, and as expected, the response of a four leg mooring appears to be quite independent of current direction.

Due to its complexity and related increased cost, the 4 leg mooring was not retained as a good building block to use in the construction of more complex cable arrays.

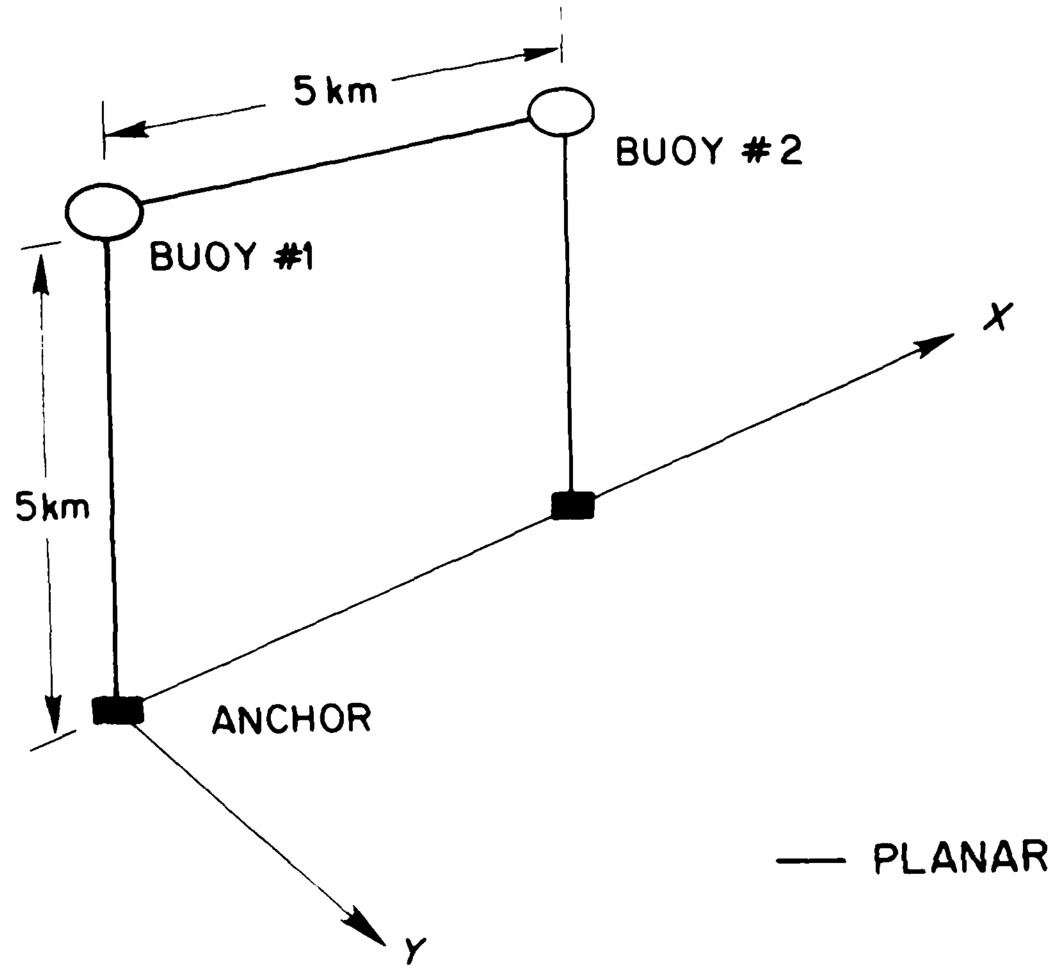
PLANAR ARRAYS

Planar arrays can be defined as cable structures entirely contained in one plan when not subjected to current action. Inasmuch as complex arrays may well incorporate horizontal or nearly horizontal cable members it seemed reasonable to first investigate the effects that such cables have on the stability of simpler arrays. To this end three types - the "C", the "E", and the "EX" - were studied.

A "C" array can be described as one having two buoys, each with a vertical anchoring line and both connected by a third, nearly neutrally buoyant, cable. All three legs being approximately of equal length the array geometry somewhat reproduces a letter "C". Such an array is shown in Figure 15. An "E" array, shown in Figure 16, has three buoys, three vertical anchoring lines and two horizontal legs In the "EX" array (Figure 17), the anchoring lines of the first and last buoy are "extended" or angled out to provide for more stability in the plan of the array.

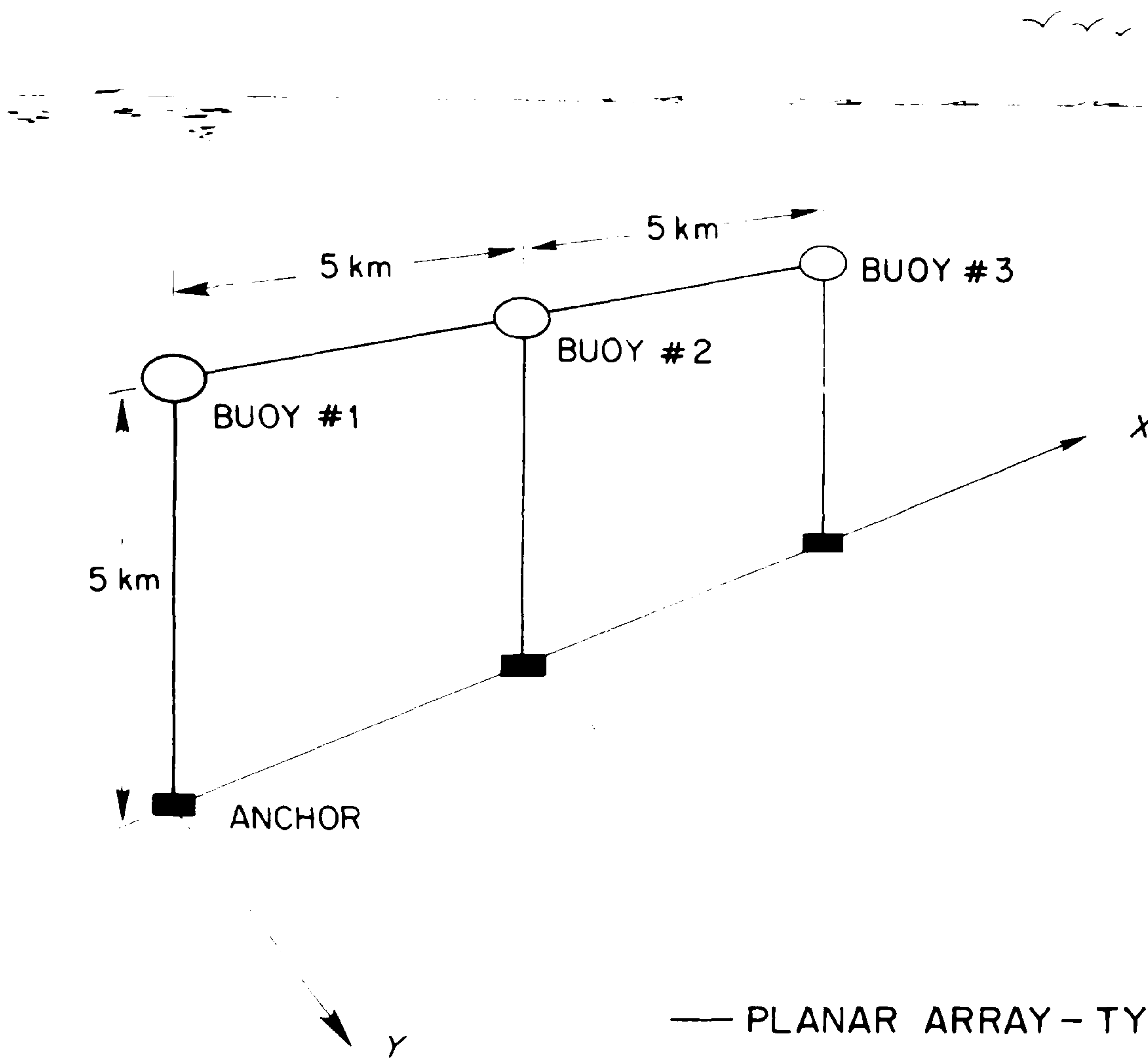
For the analysis of these arrays the following common assumptions were made.

- All buoys had a 10,000 lb buoyancy
- All cables were considered rigid first and then compliant, Dimensions as shown on Figures.
- Two current directions were used: in the plan of the array and then normal to the plan of the array.



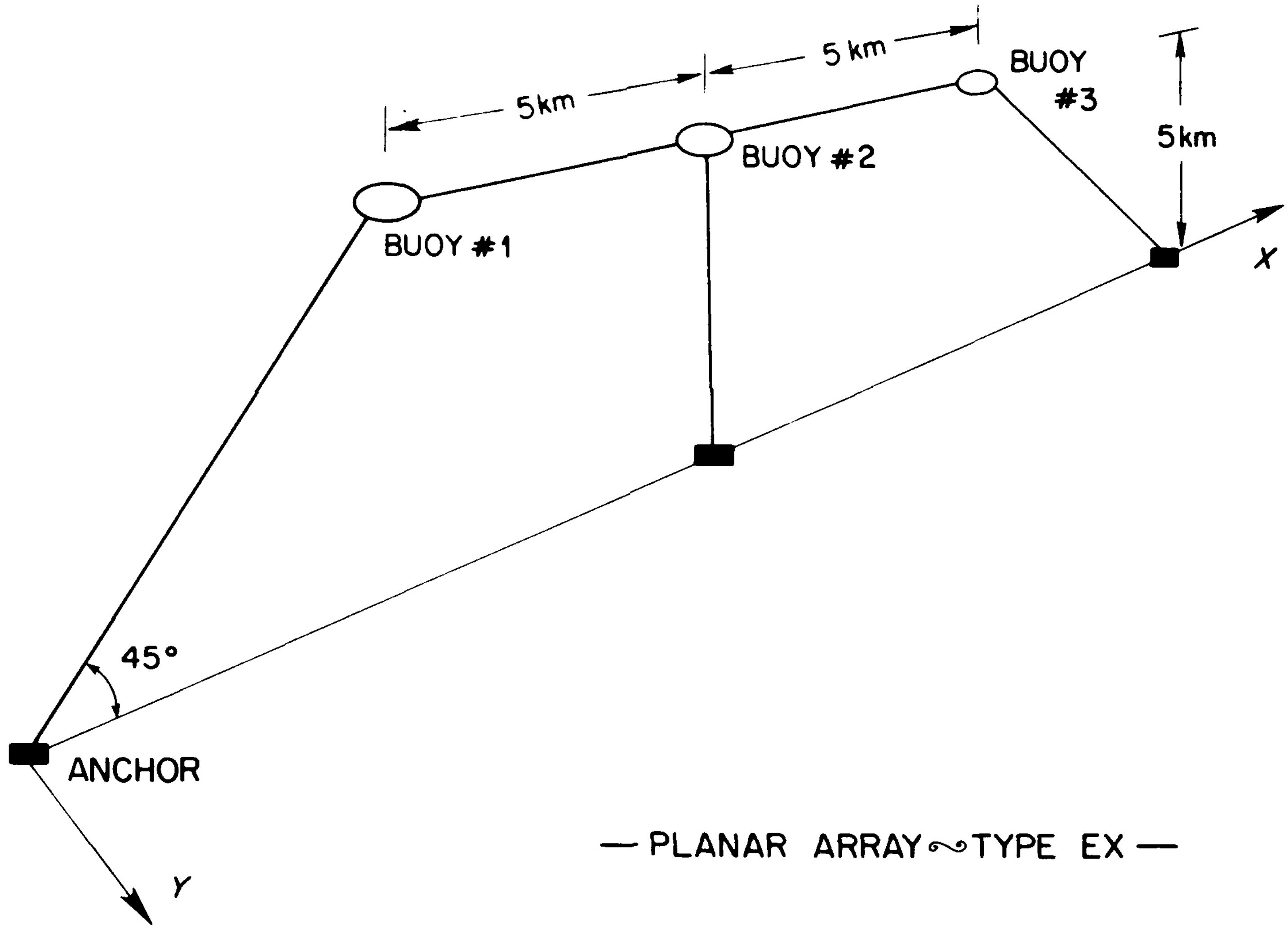
— PLANAR-TYPE C —

Figure 15



— PLANAR ARRAY - TYPE E —

Figure 16



— PLANAR ARRAY ~ TYPE EX —

Figure 17

Computation results are hereafter tabulated.

"C" ARRAY

$E = \infty$

Current Angle from X axis (Degrees)	BUOY #	X Disp (meters)	Y Disp (meters)	Z Disp (meters)	TOTAL Disp (meters)
0	1	95.09		-1.52	5.10
	2	95.09		-0.31	95.10
90	1	220.35	297.17	-14.93	370.01
	2	-220.36	297.25	-14.93	370.01

$E = 5x10^5$ psi

0	1	158.67		- 8.96	158.92
	2	164.74		4.11	164.79
90	1	24.2	341.05	-10.87	342.08
	2	-24.2	340.96	-10.87	341.99

"E" ARRAY

$E = \infty$

Current Angle from X axis (Degrees)	BUOY #	X Disp (meters)	Y Disp (meters)	Z Disp (meters)	TOTAL Disp (meters)
0	1	109.72		-8.84	110.03
	2	113.38		-1.22	113.40
	3	112.47		+6.4	112.65
90	1	23.16	272.78	-9.14	273.7
	2		384.03	-14.93	384.33
	3	-23.16	272.78	-9.14	273.7

$E = 5x10^5$

0	1	153.24		-11.31	153.65
	2	163.46		-2.9	[illegible]3.48
	3	157.24		6.37	157.36
90	1	52.27	382.54	-16.31	386.43
	2		587.84	-29.93	588.60
	3	-52.27	382.99	-16.15	386.87

"EX" ARRAY

E = ∞

Current Angle from X axis (Degrees)	BUOY #	X Disp (meters)	Y Disp (meters)	Z Disp (meters)	TOTAL Disp (meters)
0	1	39.01		-40.84	56.39
	2	39.01			39.01
	3	39.01		40.0	55.78
90	1	2.44	422.43	-20.73	422.73
	2		474.25	-22.86	474.86
	3	-2.44	422.13	-20.73	422.74

$E = 5x10^5$

0	1	95.89		-77.23	123.12
	2	103.51		- 1.23	103.52
	3	95.64		75.31	121.73
90	1	3.26	655.2	-39.1	656.37
	2		661.75	-40.44	662.98
	3	-3.28	655.2	-39.1	656.37

From these results the following conclusions can be drawn:

- Considering first the response of the planar arrays when the current is flowing in the X direction one may note that the downstream displacements of the two buoys of the "C" array and of the three buoys of the "E" array are approximately equal. Furthermore this displacement is at least one order of magnitude larger than the depth changes.

  Because of its geometry the "EX" array deformation in the X direction is found to be quite different. The X displacements are reduced to between one-third and one-half of those experienced by the "C" and "E" arrays. Furthermore the upstream buoy sinks by an amount approximately equal to its downstream excursion, the downstream buoy raises by an equal amount whereas the depth of the center buoy does not practically change. In a way the "EX" array undergoes the largest linear distortion.

- Considering next the response of the planar arrays when the current is flowing normal to the plan of the array, it is interesting to see that the downstream displacements in the Y direction are from two to three times as large as those experienced in the X direction by the buoys of the "C" and "E" array.

  Being longer the "EX" array experiences more normal drag forces and thus moves downstream even more. The Y motion of its buoy is from six to ten times greater than the X motion.

In the three arrays the Y displacement is larger than the dip by again an order of magnitude. The middle buoy of the "E" and "EX" arrays is the one experiencing the largest Y displacement.

Comparing the response of the planar arrays to the response of the single buoy arrays previously described brings about the following remarks:

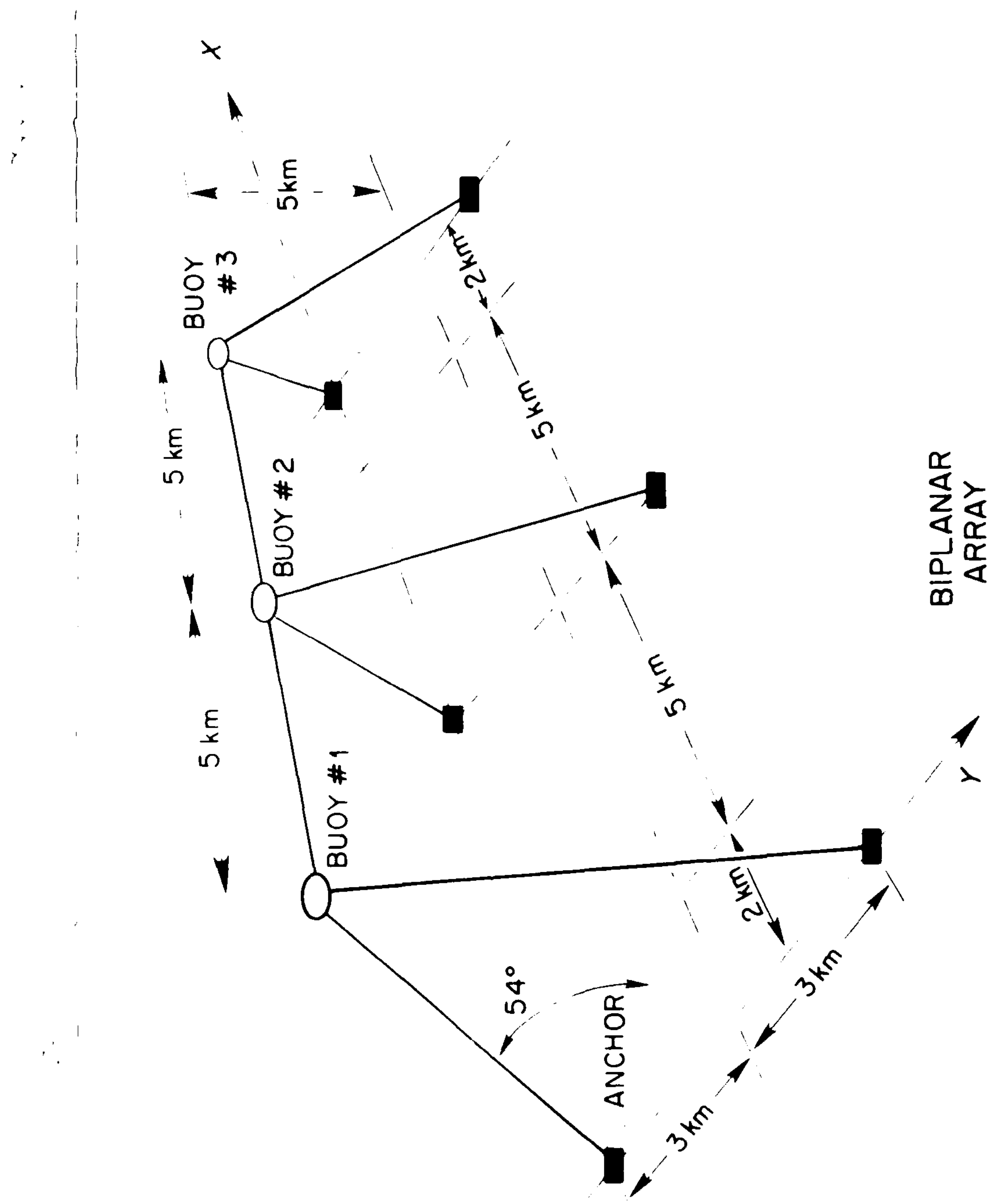
- With the current in the X direction the maximum downstream motion of the 10,000 lb buoys of a compliant single point moor, bimoor, trimoor, "C" array, "E" array, and "EX" array, are respectively: 134, 10, 38 165, 163, and 39 meters.

- With the current in the Y direction the same maximum displacements are now: 134, 389, 37, 341, 588 and 662 meters.

These numbers drastically point out the detrimental effect on stability introduced by horizontal cable members. They clearly show how poor planar arrays are with the exception of the "EX" array when acted on by currents in the X c...ection. Perhaps the combination of two "EX" arrays normal to each other (Cross Array I) constitutes a compromise worthy of further investigation.

BIPLANAR ARRAYS

Biplanar arrays were studied next. The first, in the shape of a tent as shown in Figure 18, consisted of three buoys connected by two horizontal cable members and each moored by two anchoring lines. The legs of the two end buoys were angled outwards to better resist the current flowing in the X direction. With the current flowing in the Y direction array stability was insured by the three upstream legs. The buoyancy of each of the three buoys was set at 10,000 lbs. Results obtained with rigid and compliant leg material are presented hereafter.



BIPLANAR
ARRAY
(TENT)

Figure 18

"TENT" ARRAY
E = ∞

Current Angle from X axis (Degrees)	BUOY #	X Disp (meters)	Y Disp (meters)	Z Disp (meters)	TOTAL Disp (meters)
0	1	207.25		-92.96	227.06
	2	206.34		- 5.18	206.34
	3	206.34		81.38	221.58
90	1	13.41	.91	- 5.79	14.63
	2			- .61	.61
	3	-13.41	.90	- 5.79	14.63

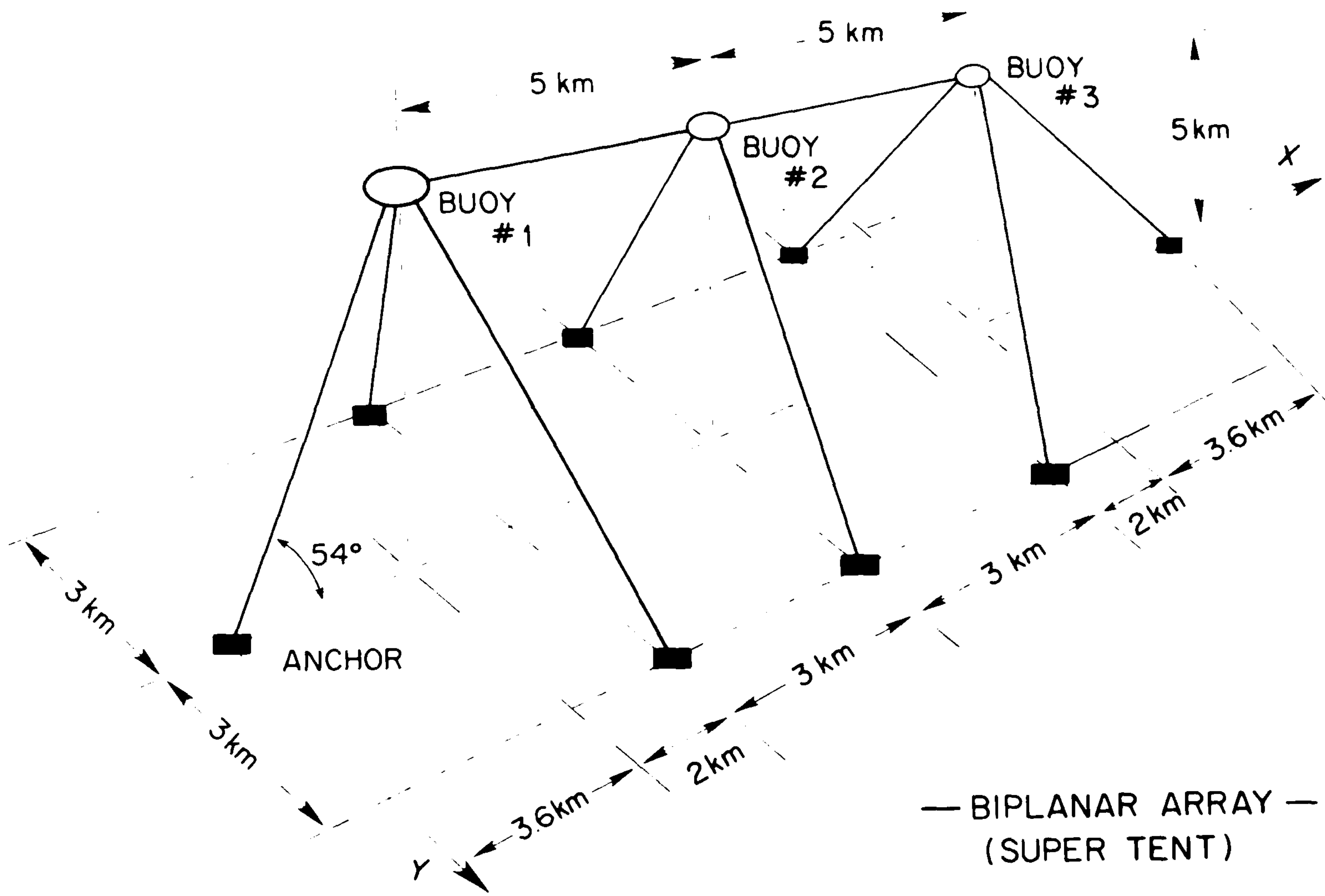
$E = 5x10^5$

0	1	274		-110.03	295.03
	2	277.05		-8.53	277.35
	3	276.14		93.57	291.37
90	1	19.81	69.8	-7.31	72.84
	2		89.3		89.3
	3	-19.81	69.49	-7.31	72.54

These results show that the pattern of buoy displacement in the X direction is similar to the one previously obtained for the planar three buoy array. All three buoys move downstream roughly an equal amount, the upstream buoy sinks, the middle one also sinks but to a much lesser extent, and the downstream buoy rises towards the surface. Surprisingly the X displacements experienced by the buoys of the "tent" array are much larger than those of the "EX" array.

With the current flowing in the Y direction, the "tent" array naturally performs much better than the planar arrays. As an example, the maximum downstream motion experienced by the middle buoy of the compliant array is found to be seven times smaller than the one experienced by the same buoy of the "EX" array. Finally, with displacements in the X direction at least four times as large as in the Y direction the "tent" array seems highly sensible to current direction.

Using a trimoor rather than a bimoor to anchor the end buoys of a "tent" array should result in a much improved array stability. To verify and quantify this reasoning the displacements of the array depicted in Figure 19 were obtained, the mooring being assumed compliant. As evidenced by the results tabulated below, buoy displacements were considerably reduced, hence the name "supertent" given to this configuration.



— BIPLANAR ARRAY —
(SUPER TENT)

Figure 19

SUPERTENT ARRAY
$E = 5x10^5$

Current Angle from X axis (Degrees)	BUOY #	X Disp (meters)	Y Disp (meters)	Z Disp (meters)	TOTAL Disp (meters)
0	1	50.69		2.04	50.9
	2	90.37		-0.70	90.52
	3	53.12		-2.62	53.34
90	1	23.26	80.55		83.82
	2		89.67	-0.21	89.91
	3	-21.94	82.84	-0.09	85.64

The good features evidenced by these numbers include:

- o Reduction of the X displacement of buoys #1 and #3 by a factor of 5 and of buoy #2 by a factor of three.
- o Considerably less sensibility to current direction.

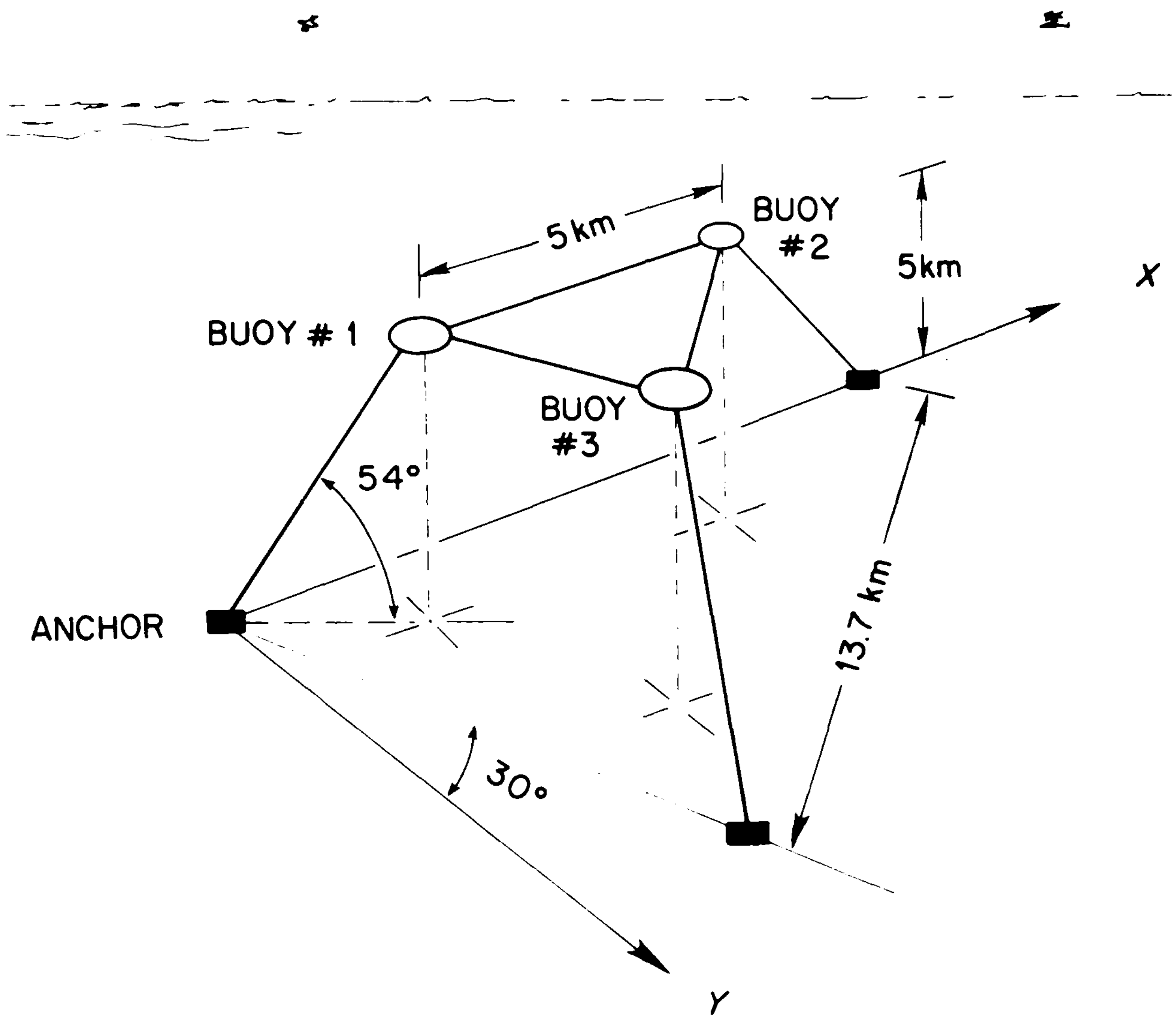
TRUNCATED PYRAMIDS

Truncated regular pyramids of triangular and square cross sections were considered next. Such arrays are depicted in Figure 20 and Figure 21. In these configurations the buoys are connected by nearly buoyant and horizontal cables each five kilometers long. These cables provide the necessary sensor support for large and small scale measurements made in the horizontal plane containing the apex buoys. The arrays are kept symmetrical to provide for better stability.

Four study cases were made of these two array configurations. These study cases had the following main features:

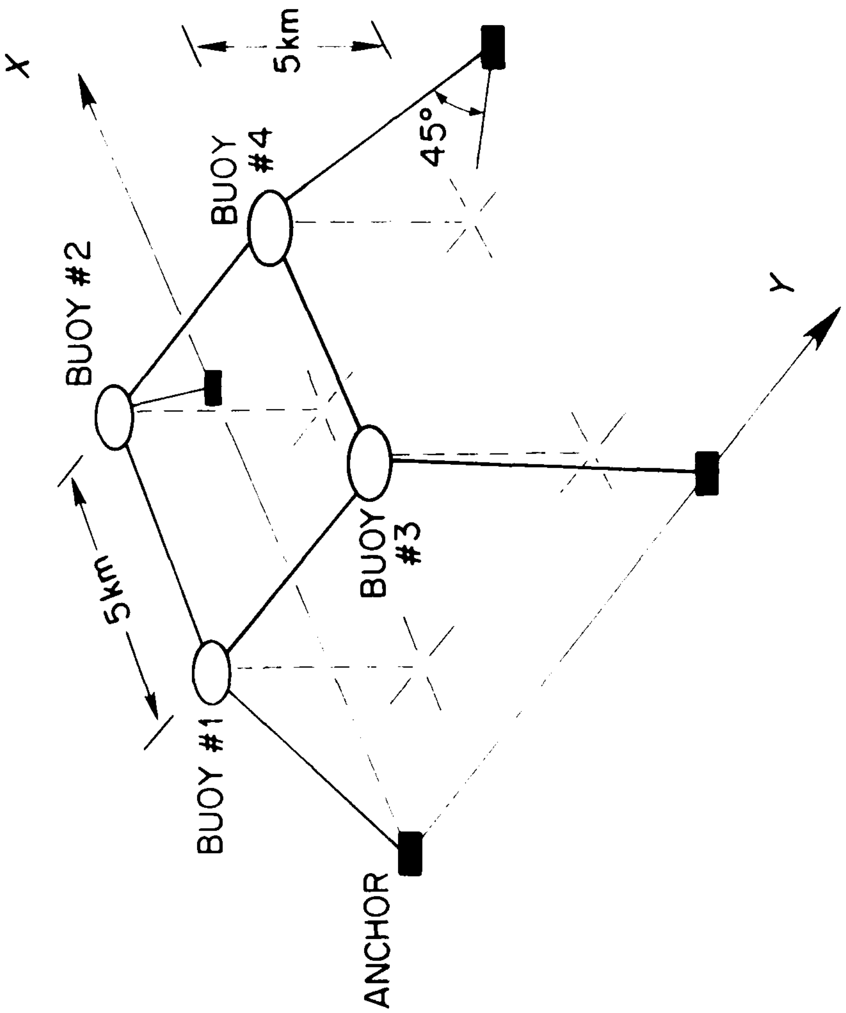
- o Triangular pyramid. Rigid. All buoys 10,000 lbs buoyancy. Current at 0, 30, 60 and 90 degrees from the X axis.
- o Triangular pyramid. Compliant. All buoys 10,000 lbs. Current as in preceding case.
- o Square pyramid. Rigid. All buoys 10,000 lbs. Current at 0 and 45 degrees from the X axis.
- o Square pyramid. Compliant. All buoys 15,000 lbs. Current as in preceding case

Results from these four study cases are hereafter tabulated.



— TRUNCATED TRIMOOR —

Figure 20



TRUNCATED SQUARE PYRAMID

Figure 21

TRUNCATED TRIANGULAR PYRAMID ARRAY
$E = \infty$

Current Angle from X axis (Degrees)	BUOY #	X Disp (meters)	Y Disp (meters)	Z Disp (meter)	TOTAL Disp (meters)
0	1	160.01		-143.86	214.87
	2	152.30		129.23	199.63
	3	165.5	-7.31	-11.28	165.8
30	1	135.63	76.02	-162.15	225.24
	2	130.45	84.73	67.36	169.96
	3	138.07	70.71	67.66	169.46
60	1	80.46	138.07	-143.86	214.87
	2	76.5	146.3	- 10.36	165.19
	3	74.37	133.19	129.84	200.24
90	1	2.13	156.96	-84.12	177.99
	2	2.13	156.96	-84.12	177.99
	3		150.26	146.3	209.69

TRUNCATED TRIANGULAR PYRAMID ARRAY
$E = 5x10^5$

Current Angle from X axis (Degrees)	BUOY #	X Disp (meters)	Y Disp (meters)	Z Disp (meters)	TOTAL Disp (meters)
0	1	313.01	-11.58	-189.58	366.05
	2	304.18	5.85	169.48	348.06
	3	339.23	-14.43	-24.08	340.14
30	1	254.19	146.91	-206.64	348.73
	2	259.98	172.81	84.73	323.38
	3	300.82	138.98	84.43	323.07
60	1	146.30	277.05	-189.58	366.05
	2	156.96	300.52	-23.47	339.84
	3	156.96	260.90	169.31	348.06
90	1	- 4.57	326.12	-121.61	348.06
	2	4.57	326.12	-121.61	348.06
	3		297.47	195.06	355.68

TRUNCATED SQUARE PYRAMID ARRAY
E =

Current Angle from X axis (Degrees)	BUOY #	X Disp (meters)	Y Disp (meters)	Z Disp (meters)	TOTAL Disp (meters)
0	1	179.21	1.52	-135.32	224.32
	2	172.81	-1.52	117.34	208.78
	3	179.21	3.66	-135.32	224.32
	4	172.81	-3.66	117.65	208.80
45	1	96.92	96.92	-143.86	188.42
	2	94.48	106.07	-10.67	142.33
	3	106.07	94.18	-10.67	142.33
	4	101.08	101.8	142.64	202.38

E = $5x10^5$

0	1	286.08	-3.05	-128.62	314.23
	2	283.45	6.71	112.77	305.09
	3	286.05	3.35	-128.92	313.93
	4	283.15	-6.71	112.17	309.79
45	1	161.84	161.84	-144.47	270.34
	2	166.41	176.47	-10.06	242.91
	3	175.86	166.41	-10.06	242.61
	4	166.91	166.41	138.68	273.09

Conclusions that can be drawn from this extensive set of data are as follows:

o As evidenced in the two runs obtained for the triangular pyramid array it appears that the three apex buoys undergo sensibly the same amount of displacement irrelatively of current direction. To be specific, in the rigid case, of all buoy displacements computed the largest one is found to be only 26.4% larger than the smallest one. This percentage reduces to 11.75% in the compliant case. It thus appears that the triangular array is reasonably omnidirectional.

o As far as the square pyramid is concerned, the same comment applies but to a lesser extent. The apex buoys undergo the largest displacements when the current is in the X direction. Deflections for the rigid array are then 36% larger than those obtained when the current is at 45 degrees.

o When comparing the rigid triangular array with the rigid square array, both having 10,000 lb buoys, one notes with interest that the displacements obtained are practically the same. As a matter of fact the mean displacement of the buoys is found to be 190.5 and 193.7 meters respectively.

- When comparing the 15,000 lb compliant square array with the 10,000 lb compliant triangular one finds that the mean displacement of the triangular array (346.84 meters) is only 18.27% larger than the mean displacement of the square array (283.45 meters). Thus it seems that the large 50% increase in buoyancy of the square array buoys does not produce a considerably more stable array. These two last comments point out that unless a fourth horizontal leg is required, the triangular array being simpler would be the configuration to favor.

Figure 22 depicts the distortions experienced by the square pyramid array while subjected to the operational current flowing in the X direction.

CROSS ARRAYS

As the name suggests, cross arrays are made of simpler arrays intersecting each other at right angles. Such arrays permit the implantation of long lengths of horizontal cables. Being of symmetrical geometry their stability should be reasonably free of current orientation effects. Two cross arrays were considered in this last case study. Cross Array I shown in Figure 23, is made of two "EX" arrays crossing each other at right angles. In Cross Array II, Figure 24, the end buoys are moored with two legs rather than one. These two legs have the same dimenstion and orientation as the end legs of the "tent" array.

The two cross arrays have five buoys each. All five buoys are assumed to have 10,000 lbs of buoyancy each. Again the current induced deflections are computed for rigid and compliant cable materials, and for currents flowing at 0 and 45 degrees from the X axis. Results are presented in the tables below.

TRUNCATED PYRAMID ARRAY
CURRENT INDUCED DEFLECTIONS

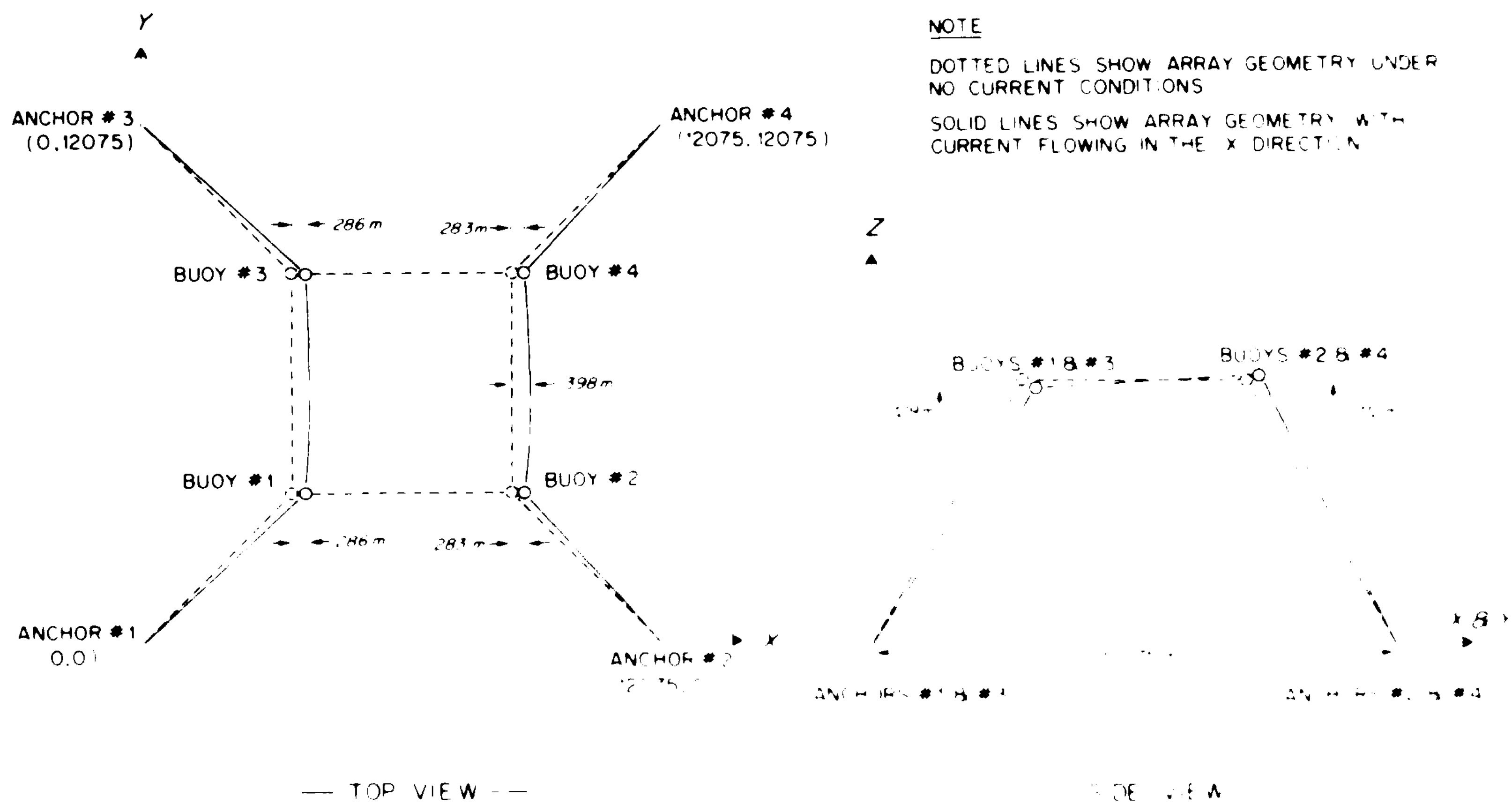


Figure 22

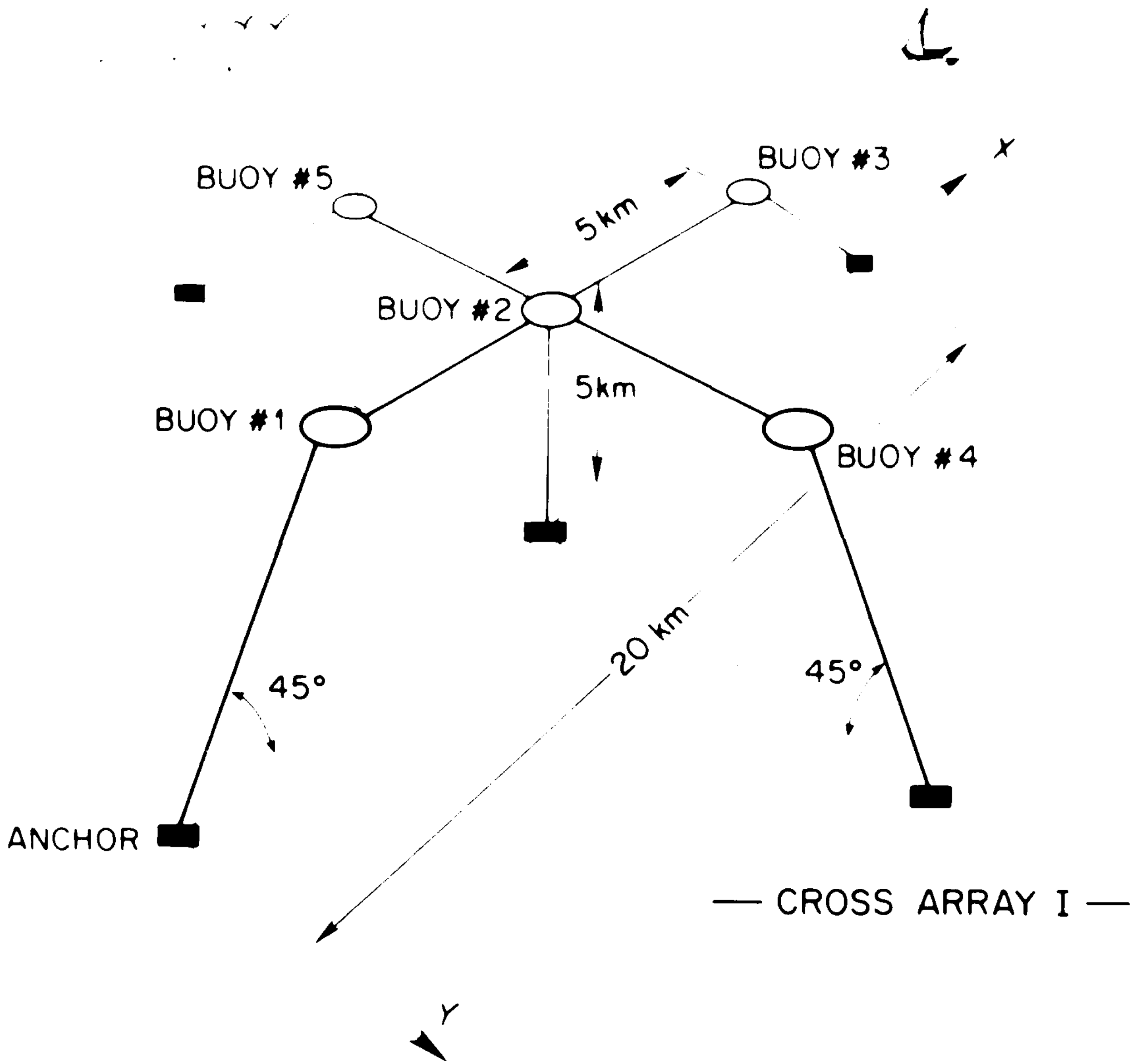
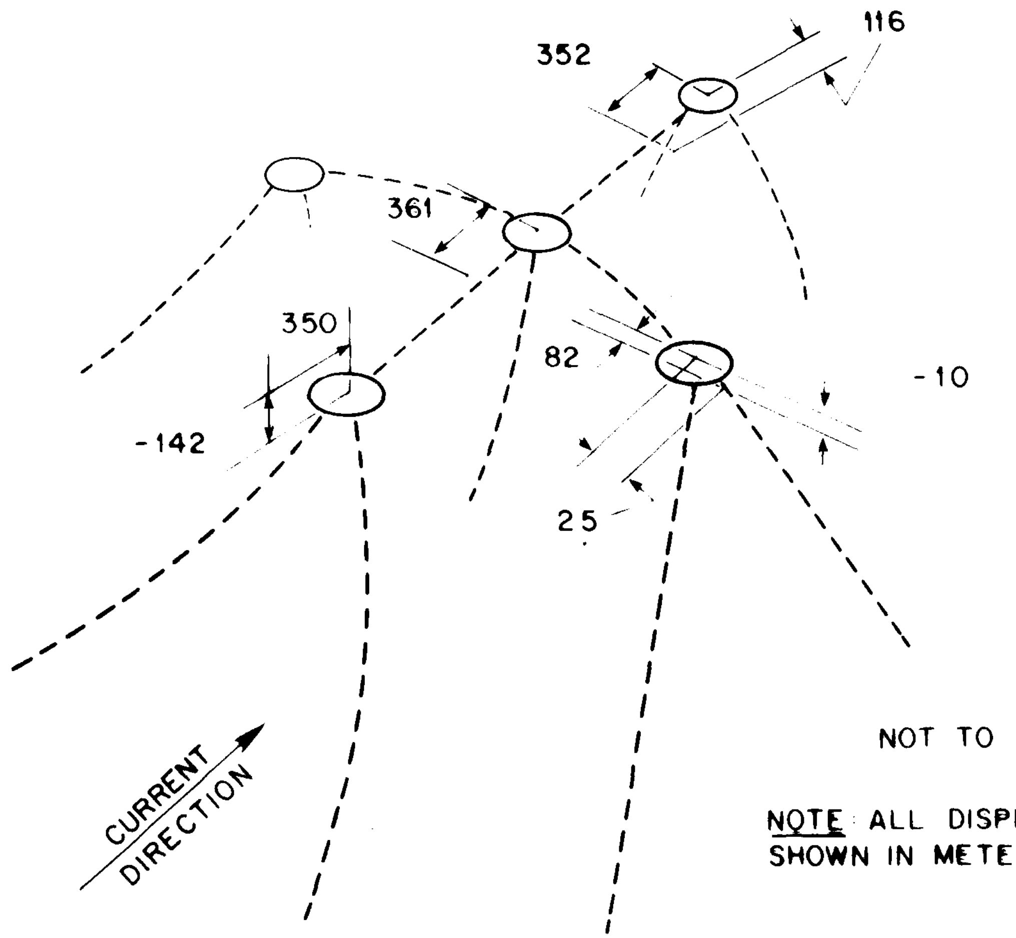
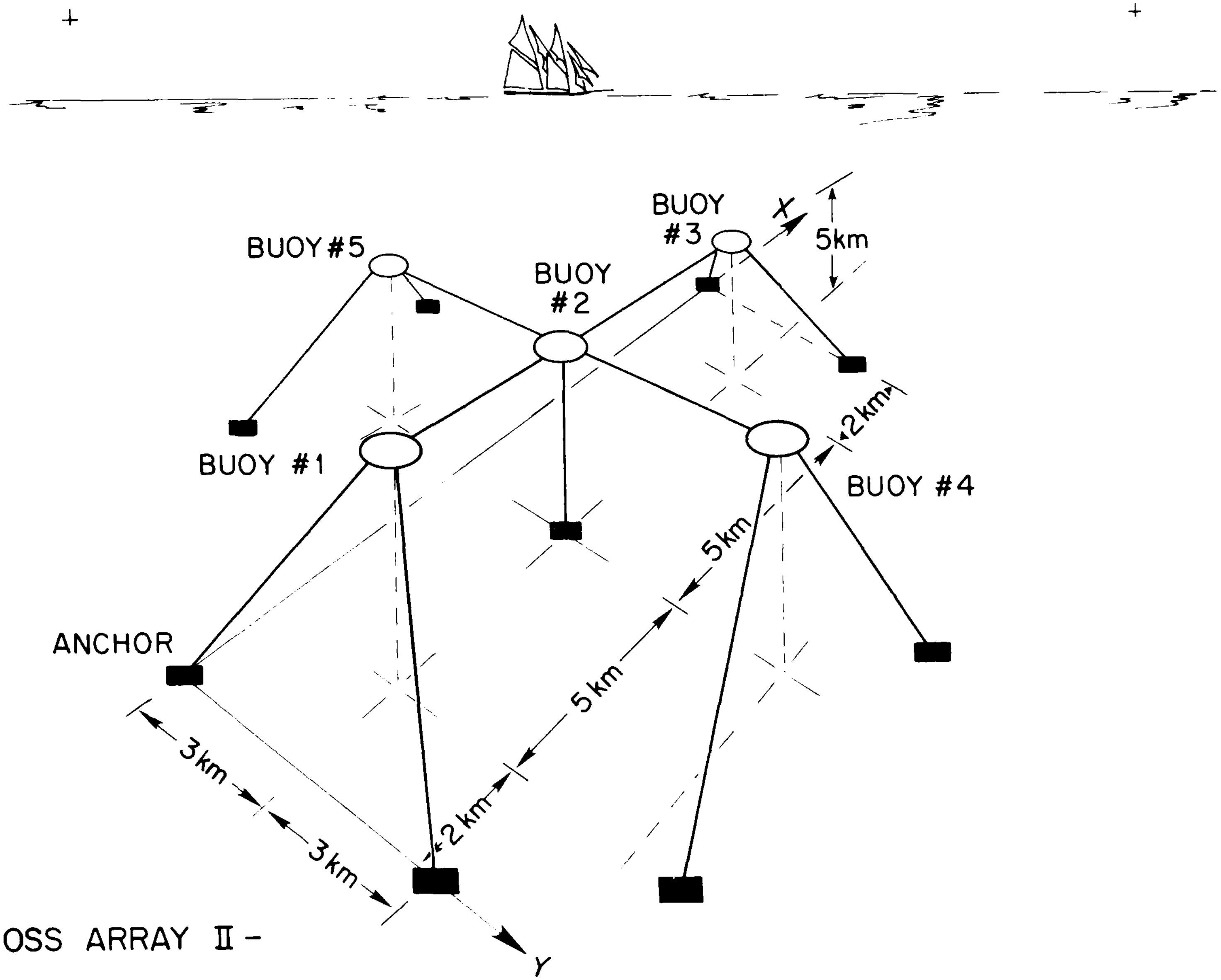

BUOY #5
BUOY #3
5km
BUOY #2
5km
BUOY #1
BUOY #4
20 km
45°
45°
ANCHOR
X
Y
— CROSS ARRAY I —

Figure 23



NOT TO SCALE

NOTE: ALL DISPLACEMENT SHOWN IN METERS.



- CROSS ARRAY II -

Figure 24

CROSS ARRAY I

E = ∞

Current Angle from X axis (Degrees)	BUOY #	X Disp (meters)	Y Disp (meters)	Z Disp (meters)	TOTAL Disp (meters)
0	1	149.95		-158.18	217.92
	2	149.95		-1.89	149.96
	3	145.38		145.08	205.12
	4	273.09	-3.54	-12.19	273.39
	5	273.09	3.54	-12.19	273.39
45	1	88.08	141.12	-93.87	190.8
	2	87.78	87.78	-1.52	124.05
	3	84.43	162.76	82.6	200.85
	4	162.96	84.46	82.6	200.85
	5	141.12	88.08	-93.87	190.8

$E = 5x10^5$

0	1	289.85		-222.49	365.13
	2	327.34		-11.89	327.64
	3	285.89		204.79	351.42
	4	501.68	-5.18	-24.69	502.29
	5	501.68	5.18	-24.69	502.29
45	1	173.12	274.31	-137.76	352.33
	2	193.23	193.23	-9.14	273.39
	3	168.55	299.91	114.9	362.69
	4	299.91	168.55	114.9	362.69
	5	274.31	173.12	-137.76	352.33

CROSS ARRAY II

$E = \infty$

Current Angle from X axis (Degrees)	BUOY #	X Disp (meters)	Y Disp (meters)	Z Disp (meters)	TOTAL Disp (meters)
0	1	249.01		-112.47	273.90
	2	250.84		-7.01	250.86
	3	247.18		96.31	265.16
	4		-17.68	-7.31	19.2
	5		+17.68	-7.31	19.2
45	1	155.14		-68.27	169.46
	2	151.48	151.78	-5.18	214.26
	3	143.25		57.91	154.22
	4		143.55	57.91	154.53
	5		155.14	-68.27	-169.46

$E = 5x10^5$

0	1	350.5		-142.03	377.93
	2	361.17		-13.41	116.43
	3	352.64		116.43	371.23
	4	81.99	-25.6	-9.45	86.25
	5	81.99	25.6	-9.45	86.25
45	1	220.05	46.33	-85.64	240.48
	2	218.23	218.23	-10.36	308.75
	3	205.12	53.34	70.1	223.1
	4	52.12	205.73	70.41	223.41
	5	46.94	220.05	-85.95	240.78

Based on the results the following comments may be formulated.

- Considering first the response of the cross arrays to the current flowing in the X direction, one may note that in either array buoys 1, 2 and 3, which are in line with the current, move downstream an equal amount. On the other hand the end buoys (buoys 4 and 5) of Cross Array I which have only one anchoring line, move downstream as much as 14 times more than the end buoys of Cross Array II. Furthermore depth changes experienced by the buoys of Cross Array I are found to be approximately twice as large as those of Cross Array II. Thus it seems that Cross Array I is much more distorted than Cross Array II.

- When the current flows at 45 degrees from the X axis the two arrays respond quite differently. In the simpler array the displacement of the four corner buoys is found to be larger than the displacement of the center buoy. In Cross Array II the reverse situation prevails. The center buoy moves more than the corner buoys and also more than the center buoy of the first array.

- When comparing the response in the X direction of Cross Array I with the "EX" array, it is interesting to note that the downstream excursion of the three buoys in line with the current follow the same pattern in either case. However the displacements of buoys 1, 2 and 3 of Cross Array I are much larger than those experienced by the buoys of the "EX" array.

- When comparing the response in the X direction of Cross Array II with the "tent" array, a similar pattern of displacement is again noted for buoys 1, 2 and 3. However the magnitude of these displacements is almost the same for both arrays. The resulting distortion is depicted in the transparency superimposed on Figure 24.

- The mean displacement of the five buoys of Cross Array I and II are as shown in the following table.

Cross Array	Cable Elasticity	Mean Displacement (meters) Current @ 0 degrees from X	Current @ 45 degrees from X
I	Rigid	224.02	181.35
	Compliant	409.63	340.14
II	Rigid	165.5	172.39
	Compliant	256.63	247.18

This table points out clearly that Cross Array II has smaller and more evenly distributed mean displacements. This probably makes it a better array than Cross Array I.

4.5 DISCUSSION OF RESULTS - SELECTION OF CANDIDATE PROTOTYPE ARRAY

The case studies just completed have placed emphasis on array stability. Motions of apex buoys have been computed and an attempt at comparing the stability of different arrays sharing common structural specifications has been made.

Criteria to strictly define stability are subjective. For some total displacement would be the main concern. Others may want to minimize vertical displacements only. Others still may be concerned with linear or planar distortion of the array.

As another criterion for comparing array stability the mean of the total displacements experienced by the buoys of the more interesting arrays just analyzed has been computed. These results, which all apply to compliant case studies, are tabulated hereafter.

Type of Array	Mean Total Displacement of Buoys in Array(meters)
Trimoor	38.36
Tent Array	183.07
Supertent Array	75.69
Truncated Triangular Pyramid	346.26
Truncated Square Pyramid	284.0
Cross Array I	375.16
Cross Array II	227.46

Based on this averaging process, and with the exception of the trimoor, the supertent array clearly stands out as the most stable.

However criteria other than stability must also be considered when selecting an array configuration. A "good" array should not only be stable but it should also certainly have the desirable features mentioned below:

- Allow for close as well as large spacing of instruments.
- Allow measurements to be made orthogonally.
- Respond independently of current direction.
- Be of relative simplicity to permit ease of analysis, design, deployment and servicing.

The supertent array, in the configuration presented, is not as versatile as other configurations. It is of relative complexity. It has only two horizontal cable members and eight anchoring lines. It has no orthogonal symmetry.

A combination of two supertents could however constitute an excellent array. They could be placed at right angles to each other. Or two supertents could be placed say one or two hundred kilometers apart.

The Cross II Array seems to embody many desirable features in its design and performances. It may not be the ultimate array, but it has excellent scientific potential, it has the best stability of all other two-dimensional configurations considered, it is not too complex, and it <u>can</u> be deployed. It thus offers a good working compromise. The Cross II will be studied further.

The design and deployment scenario of the Cross Array II as outlined in the following sections are typical of the design procedure and deployment techniques that similar complicated arrays require to be successfully implanted.

5.0 <u>DESIGN OF PROTOTYPE ARRAY</u>

The main components of any deep sea structure are the buoys, the anchors, and the cables connecting them. The design of Cross Array II therefore will essentially consist in selecting the shape, size, and materials that these components should have to provide the structural stability and integrity required over the desired life.

To be both successful and reasonable the design must first consider the following:

- o Environmental loads, including survival conditions.
- o Environmental factors of deterioration.
- o Related experience and state-of-the-art.
- o Availability of materials.
- o Cost effectiveness.

These general conditions, as they apply to the array main components, are hereafter reviewed.

5.1 GENERAL DESIGN CONSIDERATIONS

5.1.1 BUOYS

Spheres are known to best resist hydrostatic pressure. The drag of spheres is well established, is independent of current orientation and relatively low. Spheres are a very effective float shape, and for this reason all buoys of the array will be assumed spherical.

Under no current conditions the buoys are at a nominal depth of 500 meters below the surface. With current application these buoys are deflected, some sinking more than others, the amount depending on the buoyancy of the buoy, the current direction and intensity, and the type of cable used. For design purposes the buoys should be strong enough to resist, with a sufficient safety margin, the external pressure reached under worst case conditions.

To provide a basis for buoy selection, three candidate materials were investigated: HY80 steel, 7075T6 aluminum, and 32 lb/cu.ft syntactic foam. Using these commonly available materials, the size, air weight, and approximate cost were established for buoys providing 5000, 10,000, and 20,000 pounds of buoyancy at a depth of 1500 meters - three times the no-current implantation depth. These figures are hereafter presented in Table 1, "Comparative Table of Buoy Parameters".

5.1.2 MOORING LINES

Mooring lines in a deep-sea array can be subjected to corrosion, fouling, fishbite, abrasion, and creep. In order to have a life of five years in the ocean a very careful choice must be made to prevent damage and consequent degradation from these causes. Ideally mooring lines and interconnecting cables used in an array of this type should have a large strength-to-weight ratio to minimize the buoyancy requirements.

The rope diameter should be small to reduce hydrodynamic drag. The rope should be protected from sea water corrosion and from attacks by fish and fouling organisms. The rope material should have low elastic stretch

TABLE 1

"COMPARATIVE TABLE OF BUOY PARAMETERS"

	BUOYANCY 5,000 POUNDS				BUOYANCY 10,000 POUNDS				BUOYANCY 20,000 POUNDS			
	DIAMETER (ft)	WALL THICKNESS(in)	AIR WEIGHT (lbs)	PRICE (Dollars) 1980	DIAMETER (ft)	WALL THICKNESS(in)	AIR WEIGHT (lbs)	PRICE (Dollars) 1980	DIAMETER (ft)	WALL THICKNESS(in)	AIR WEIGHT (lbs)	PRICE (Dollars) 1980
STEEL	7.5	.48	2238	25K	7.6	.62	4555	53K	9.6	.78	9200	115K
ALUMINUM	5.6	.55	770	50K	7.0	.69	1536	106K	8.8	.87	3070	230K
SYNTACTIC	5.7	-	5500	21.5K	8.5	-	11,000	65K	10.8	-	22,000	118K

and low and predictable creep characteristics. It should not be subject to internal abrasion or fretting. Electrical performance of the power and signal carrying cables should also be carefully considered.

- CORROSION

Many of the mooring lines and interconnecting cables must pass electrical signals which will require copper conductors. The low yield strength of copper will necessitate a high strength/modulus material be incorporated into the construction. Normally steel wires are laid in two or more layers contra-helically to provide high strength and torque balance. To reduce corrosion these wires are coated with a heavy layer of zinc. Often a polyethylene or urethane jacket is extruded around the whole cable. Such cables have lasted many years in the ocean, particularly when laying on the bottom.

The large weight is a disadvantage to this construction for an array application. High strength synthetic materials are now available which can replace the steel wire in such a cable. Aramid fibers have been substituted for the steel wires with excellent results providing lighter smaller cables which do not corrode.

- FISHBITE, FOULING

Sufficient evidence[11] exists to recognize a potential threat of damage to lines in the ocean from certain fish including sharks. This threat is present in all oceans between 41^{o}N and 41^{o}S of latitude. Damage has not been recorded deeper than 2050 meters. Cable constructions using outer armor wires of steel resist attack best. Suppression of strumming also seems to reduce incidence of attack. Synthetic materials, particularly when under tension, can be quite susceptible to damage. Synthetic lines, however, can be protected from fishbite by extrusion of very hard plastic jackets over the lines. DuPont's ZYTEL ST801 with a durometer of 60 is one such plastic which shows great fishbite protection potential.

Fouling by marine organisms does not appear to be a significant problem below the photic zone or about 200 meters. Inasmuch as the top of the array is well below this depth it will not be further considered.

- ABRASION

The cable should be constructed so that it will not be damaged while handling it during installation of the array. A tough plastic jacket will considerably reduce external abrasion. Special techniques should be employed to prevent internal abrasion damage when using a rope constructed of high-modulus synthetic yarns such as aramid fibers. Special lubricants and coatings are effective in this regard.

- STRETCH

A cable under tension will be subject to elastic stretch and creep. Elastic stretch is recoverable, i.e. it will return to its original length when the tension is removed whereas creep is permanent and generally time dependent. If electrical or light signals are to be sent through the cable both elasticity and creep must be small and predictable. High modulus materials must be used whose characteristics are compatible with the allowable strain in the conductors.

- CANDIDATE MOORING LINES

Based on the previous consideration and within the state-of-the-art only a few cable materials and cable constructions can be considered practical for deep sea array applications. They include:

- 3x19 plastic jacketed, torque balanced galvanized wire rope. Having no conductors, this rope is used strictly as a mooring line. It will resist fish bites. Its reliability has been amply demonstrated. However its use would require additional buoyancy distributed along its length.

- Steel armored torque balanced electromechanical cable. Probably best used as a conducting cable deployed on the sea floor to convey power and signals to and from the array.

- 3x19 torque balanced Kevlar rope with or without fishbite resistant plastic jacket. This rope would be used as a strong, stiff, nearly neutrally buoyant mooring leg.

- Torque balanced electromechanical Kevlar rope, with a number of conductors and with or without fishbite resistant jacket. Probably best used as a power and signal carrying horizontal cable member and/or mooring leg.

The breaking strength, the immersed weight, and the cost per meter for various sizes of these cable candidates have been summarized in Table , "Comparative Table of Cable Parameters".

5.1.3. ANCHORS

Because of the array geometry the pull exerted by the mooring lines on their anchors will have horizontal and vertical components of approximately equal magnitude. To cope with this difficult anchoring problem heavy anchors equipped with large flukes have been designed and successfully deployed. These "porcupine" or "mace" anchors are modular, consisting of several stacked cylinders of cast iron with steel raked flukes between each cylindrical slabs (Figure 25). The anchor is of high density thus reducing the stowage space on deck. Being modular, it is easier to ship and to assemble and is less expensive to fabricate. The actual size of the anchors will be determined by the worst case tension obtained from the computer study.

5.2 PROTOTYPE ARRAY - DESCRIPTION

The following is a description of the prototype array.

Given the lack of specifics on scientific purposes and stability requirements the selection of the array components may seem arbitrary. What is proposed here is a sensible, useful, reliable array of predictable

TABLE 2

COMPARATIVE TABLE OF CABLE PARAMETERS

CABLE TYPE	SIZE OD(in)	BS (lbs)	WET WEIGHT (lbs/meter)	1980 PRICE ($/m)
3x19 WIRE ROPE	.500	22,800	1.046	3.46
	.625	35,000	1.617	4.72
	.750	49.600	2.368	6.77
ELECTROMECHANICAL WIRE ROPE	.589	23.000	1.406	42.64
	.671	30,000	1.877	49.20
	1.023	72,000	4.243	59.04
KEVLAR (3x19)	.750	45,000	.099	6.82
	.875	57,000	.153	8.73
	1.00	74,000	.214	11.45
ZYTEL JACKETED KEVLAR	.890	45,000	.110	9.08
	1.015	57,000	.165	11.23
	1.140	74,000	.228	14.20
ELECTROMECHANICAL KEVLAR (3x19)	.83	45,000	.321	9.82
	.955	57,000	.375	11.73
	1.080	74,000	.434	14.45
ZYTEL JACKETED ELECTROMECHANICAL KEVLAR	.890	45,000	.335	9.85
	1.015	57,000	.391	11.77
	1.140	74,000	.454	14.50

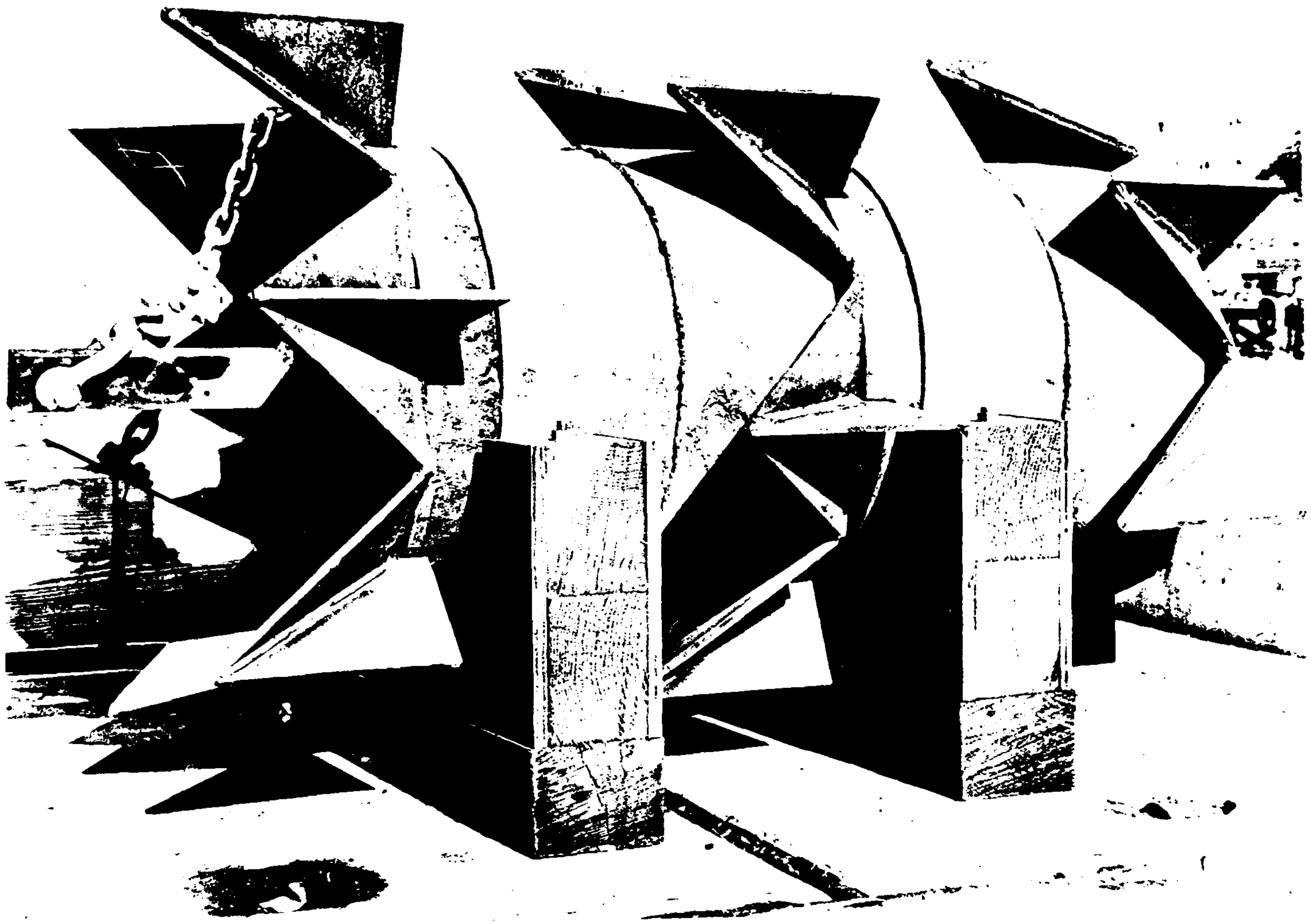


Figure 25: Typical Porcupine Anchor

stability.

BUOYS

The five buoys of the array are 8.5 feet diameter spheres made of syntactic foam with a density of 32 lbs/cu.ft providing 10,000 lbs of buoyancy per buoy. This buoyancy, as further evidenced in the computer study performed on the prototype array is adequate for good operational stability.

CABLES

The five buoys are connected to each other and to the nine anchors by thirteen cables. The four "horizontal" cables and one of the mooring legs of buoy #1 will have conductors to power the array instrument network. Others are simply used to moor the array in place.

All cables use Kevlar 29 as a strength member in their construction. They all have a nominal diameter of 0.75 inch and a breaking strength of 45,000 lbs. All cables or portions of cables above the 2000 meter depth will be jacketed with hard ZYTEL ST801 to an outside diameter of .830 inch.

The construction used is 3x19, that is the ropes are made of three strands each strand having 19 yarns. The yarns are made of wax impregnated loosely wound Kevlar filaments. Both yarns and strands use a large lay length. This combined with the fact that yarns and strands are wound in opposite directions results in a very strong and well torque-balanced construction. To ensure tight packing of the strands when the rope is not under tension the rope is covered with a braided polyester jacket.

The Kevlar electromechanical cables are of the same 3x19 construction. Insulated conductors are laid in the valleys between strands. These conductors consist of a coxial cable used for data retrieval and placed in one valley, the other two valleys being occupied by two pairs of twisted #10 gauge stranded copper wires. The latter are used to power the array sensors, one pair acting as a spare.

Figure 26 shows a cross section of the Kevlar electromechanical cable. Figure 27, a general view of the prototype array, shows where the different cable types are used.

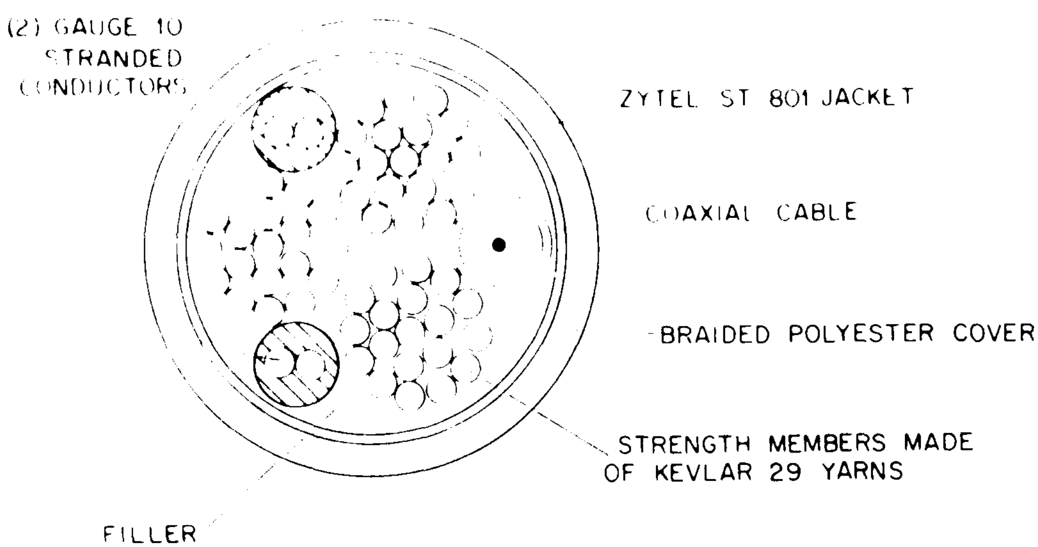
ANCHORS

Anchoring of the array is provided by nine identical "porcupine" anchors (see Figure 25). The air weight of the anchor is 17,500 lbs. The immersed weight of the anchor is 15,000 lbs.

5.3 COMPUTER STUDY

The prototype array with the components just described was analyzed again using the DESADE program. The modulus of elasticity used for all Kevlar cables had a realistic value of five million pounds per square inch (psi). Three current regimes were considered: operational

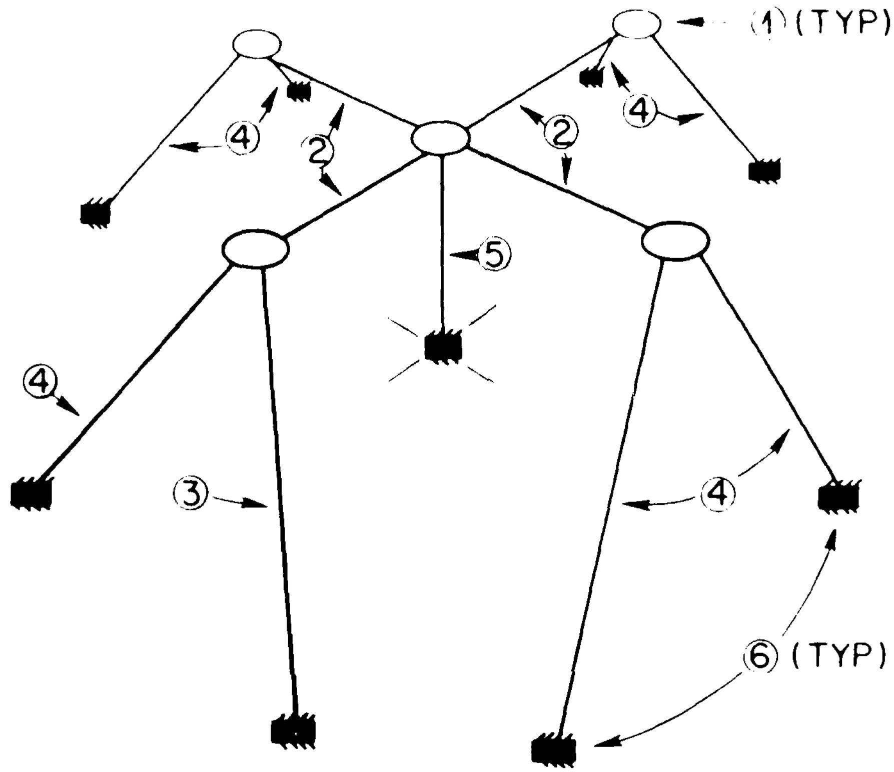
CROSS SECTION
3 x 19 KEVLAR ELECTROMECHANICAL CABLE



CABLE OUTSIDE DIAMETER = 0.890 in
CABLE BREAKING STRENGTH = 45,000 lbs

Figure 26

GENERAL VIEW AND BILL OF MATERIALS OF CROSS ARRAY II STRUCTURAL COMPONENTS



PIECE NO.	REQ'D	DESCRIPTION	LENGTH (m)	REMARKS
1	5	8.5 FT. DIAM. SPHERE, SYNTACTIC FOAM BUOY		
2	4	LENGTH OF 3/4 IN. KEVLAR E/M CABLE	5000	LENGTH OF ZYTEL COATING = 5000 m
3	1	LENGTH OF 3/4 IN. KEVLAR E/M CABLE	6166	LENGTH OF ZYTEL COATING = 2000 m.
4	7	LENGTH OF 3/4 IN. KEVLAR ROPE	6166	LENGTH OF ZYTEL COATING = 2000 m.
5	1	LENGTH OF 3/4 IN. KEVLAR ROPE	5000	LENGTH OF ZYTEL COATING = 1500 m.
6	9	17,500 lb. PORCUPINE CAST IRON ANCHOR		

Figure 27

at zero degree from the X axis, operational at 45 degrees from the X axis and survival at zero degrees from the X axis. In the survival case the current profile was assumed to be twice as large as the operational one. As an example of typical results obtained, the computer output for the first current regime is reproduced in Appendix A. Results from these three runs are further discussed in the following section.

5.4 DISCUSSION OF STUDY RESULTS

Results from the computer study will confirm, in theory at least, how sound the design of the prototype array is.

If properly designed the array should display a reasonable degree of operational stability and the components should have a reasonable margin of safety both in the operational and survival modes.

ARRAY STABILITY

The current induced displacements of the five buoys obtained under operational conditions are hereafter tabulated in the fashion previously used.

PROTOTYPE ARRAY

Current Angle from X axis (Degrees)	BUOY #	X Disp (meters)	Y Disp (meters)	Z Disp (meters)	TOTAL Disp (meters)
0	1	302	0	-137	332
	2	305	0	-10	305
	3	300	0	+114	321
	4	9	-24	-10	28
	5	9	24	-10	28
45	1	189	5	-83	206
	2	185	185	-8	262
	3	174	5	69	187
	4	5	174	69	187
	5	5	190	-84	208

From these results the following comments on the stability of the prototype array can be made.

- As expected, the response of the prototype array follows the pattern previously discussed in Section 4.4. "Case Studies, Cross Arrays".

- Increasing the cables modulus of elasticity from $E = 5 \times 10^5$ to $E = 5 \times 10^6$ will tend to reduce the displacements previously computed for the 10,000 lb buoyancy "compliant" Cross Array II case study. Increasing the cables diameter from 0.65 to 0.75 inch would however tend to make these displacements larger. Comparing the two tables of results shows that the combined effect of increased E and increased diameter change the value of the previously computed displacements by only a small amount.

o In an attempt at quantifying the array operational stability the following absolute and relative (expressed as a percentage of bottom depth) minimum and maximum computed displacements are hereafter presented. All maximum and minimum displacements occur when the current is in the direction of the X axis except for the minimum vertical displacement which occurs with the current at 45° from the X axis.

	Buoy Position	Absolute (meters)	Relative (%)
Minimum horizontal	Wing	26	.47
Maximum horizontal	Center	305	5.55
Minimum vertical*	Center	8	.15
Maximum vertical	Up Current	137	2.50
Minimum total	Wing	28	.51
Maximum total	Up Current	332	6.04

*Current at 45° from X axis

Finally the mean horizontal, vertical and total displacement of all buoys are found to be:

mean horizontal displacement = 188 meters or 3.4% of depth.
mean vertical displacement = 59 meters or 1.07% of depth.
mean total displacement = 206 meters or 3.75% of depth.

PERFORMANCE OF ARRAY COMPONENTS

Buoys. When the array is subjected to the survival current Buoy #1 experiences the largest dip. It plunges from a no current depth of 500 meters to a depth of 1050 meters. This depth is 450 meters less than the maximum working depth of 1500 meters specified for all buoys. It thus appears that the buoys as designed will resist survival conditions with a good margin of safety.

Cables. When subjected to the operational current, which in principle will prevail most of the time, a maximum tension of 8147 lbs occurs at the top of the cable anchoring the center buoy to the sea floor with the current flowing along the X axis. The minimum tension prevailing at this time occurs at the downcurrent end of the downcurrent horizontal leg and has a value of 3344 lbs. The corresponding minimum and maximum cable safety factors are then 5.3 and 13.5 respectively. Based on past experience and on manufacturers recommendations a safety factor of 5 should be adequate for Kevlar ropes subjected to long term (years) submerged static applications.

Under survival conditions the maximum tension increases to 9470 lbs. The corresponding safety factor is then 4.8 which is still adequate to prevent creep and rope degradation.

Anchors. The anchors should provide ample holding power under all current conditions including survival.

The maximum anchor tension computed under survival conditions was 8559 lbs with a cable angle of 48 degrees from the horizontal. The horizontal and vertical components of this tension are thus 5727 lbs and 6361 lbs. A conservative value for the holding power of a porcupine anchor is 1.5. Using this value of holding power and a vertical component of tension of 6361 lbs, a porcupine anchor with a 15,000 lb immersed weight could resist a horizontal pull of 12,958 lbs. Under these circumstances the weight-to-lift ratio is 2.36 and the holding force to horizontal pull ratio is 2.26. It thus appears that 15,000 lbs wet weight porcupine anchors would safely hold the array in place.

6.0 DEPLOYMENT/SERVICING

6.1 ARRAY DEPLOYMENT

6.1.1 LOGISTIC CONSIDERATIONS

The deployment of deep ocean arrays requires a high capability vessel. It must be able to lift and ease overboard loads ranging from ten to twenty thousand pounds. It must have a winch with sufficient wire to reach the bottom and capable of handling heavy anchors. It must be highly maneuverable and able to maintain station during deployment operations.

The vessel must be equipped with computer facilities which can be tied into a bottom-mounted acoustic transponder network.

A workboat will be required for certain operations during deployment.

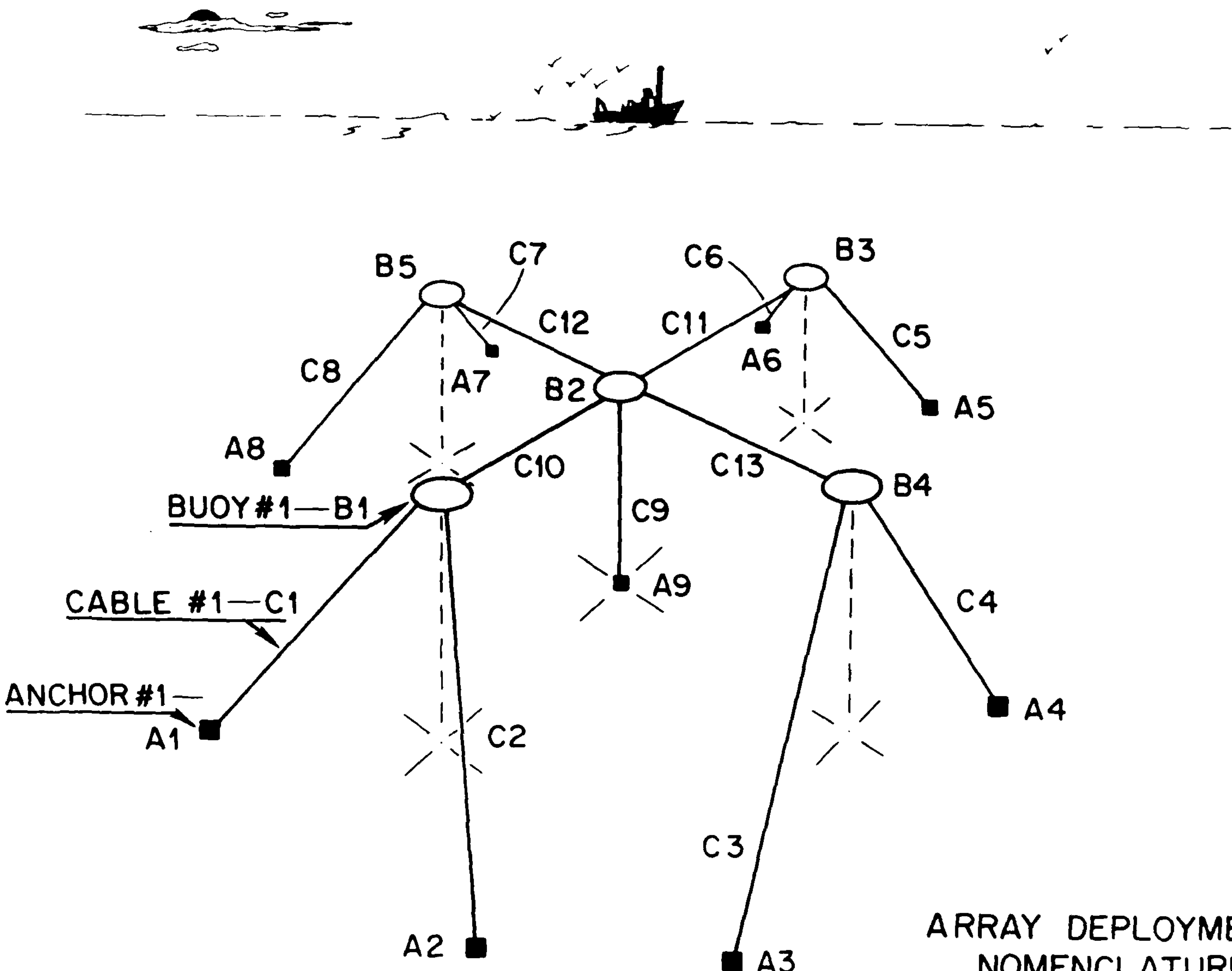
Implanting Cross Array II as hereafter outlined will require approximately three days. It is of the utmost importance to schedule the deployment at a time where good weather and calm seas will most likely prevail.

6.1.2 SITE SURVEY AND PREPARATION

Prior to the installation of the array the selected site must be thoroughly surveyed. Bathymetric soundings must be made with close grid spacing. Information on currents should be obtained using dropsonde and vessel drift data. A network of bottom mounted acoustic transponders must be set in place and surveyed in. A temporary taut surface mooring (T1) should be set at anchor position A10.

6.1.3 DEPLOYMENT SCENARIO

Figure 28 shows the anchor, cable, and buoy numbers referred to in the Cross Array II deployment scenario. Figures 29 through 33 show a view looking down on the array during various stages of the deployment operation. The specific activities for each phase are listed on each figure.



ARRAY DEPLOYMENT
NOMENCLATURE

Figure 28

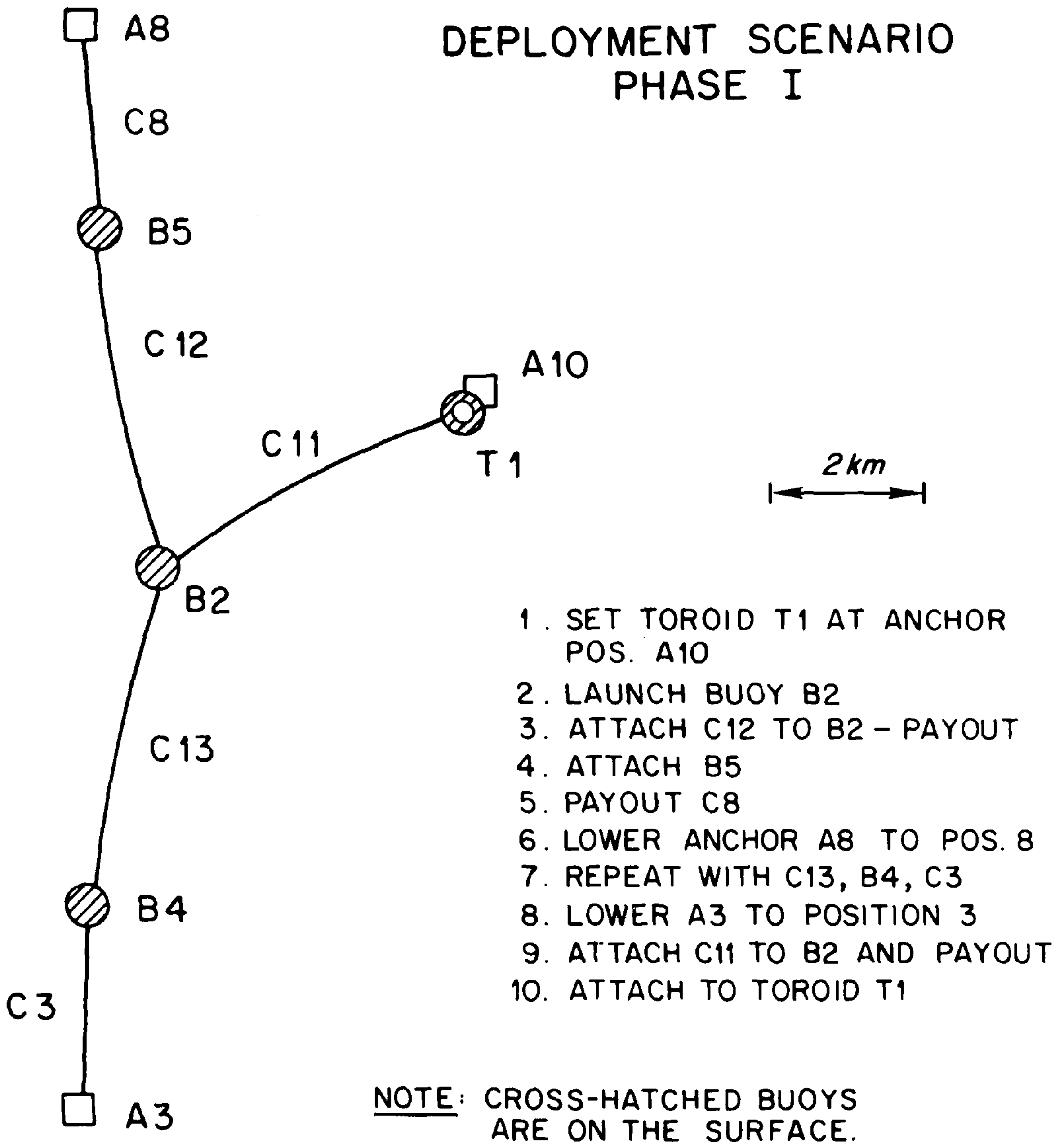

DEPLOYMENT SCENARIO
PHASE I
A8
C8
B5
C 12
A10
C 11
T 1
2 km
B2
C 13
B4
C 3
A3
1. SET TOROID T1 AT ANCHOR POS. A10
2. LAUNCH BUOY B2
3. ATTACH C12 TO B2 - PAYOUT
4. ATTACH B5
5. PAYOUT C8
6. LOWER ANCHOR A8 TO POS. 8
7. REPEAT WITH C13, B4, C3
8. LOWER A3 TO POSITION 3
9. ATTACH C11 TO B2 AND PAYOUT
10. ATTACH TO TOROID T1
NOTE: CROSS-HATCHED BUOYS ARE ON THE SURFACE.

Figure 29

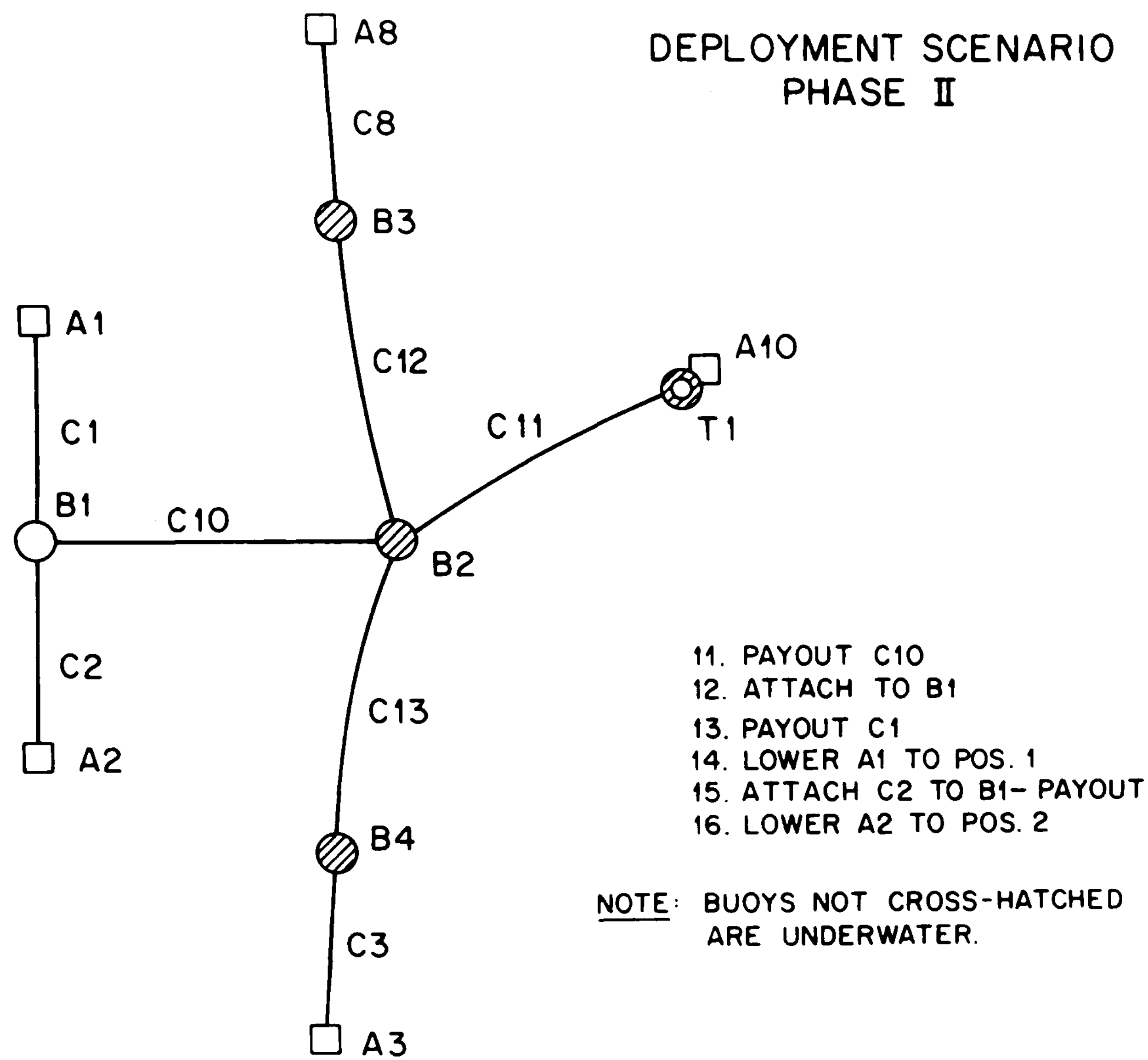
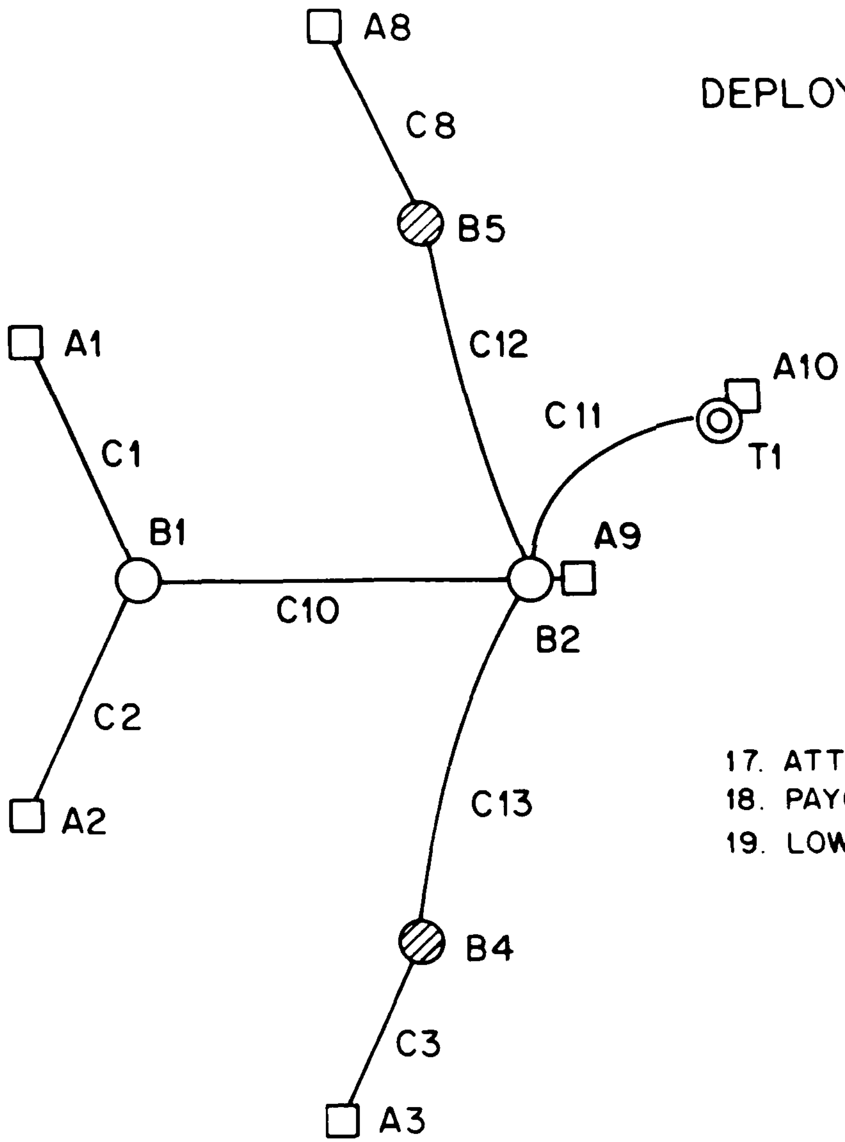

DEPLOYMENT SCENARIO
PHASE II
A8
C8
B3
C12
A1
C1
B1
C10
B2
C11
A10
T1
C2
A2
C13
B4
C3
A3
11. PAYOUT C10
12. ATTACH TO B1
13. PAYOUT C1
14. LOWER A1 TO POS. 1
15. ATTACH C2 TO B1- PAYOUT
16. LOWER A2 TO POS. 2
NOTE: BUOYS NOT CROSS-HATCHED
ARE UNDERWATER.

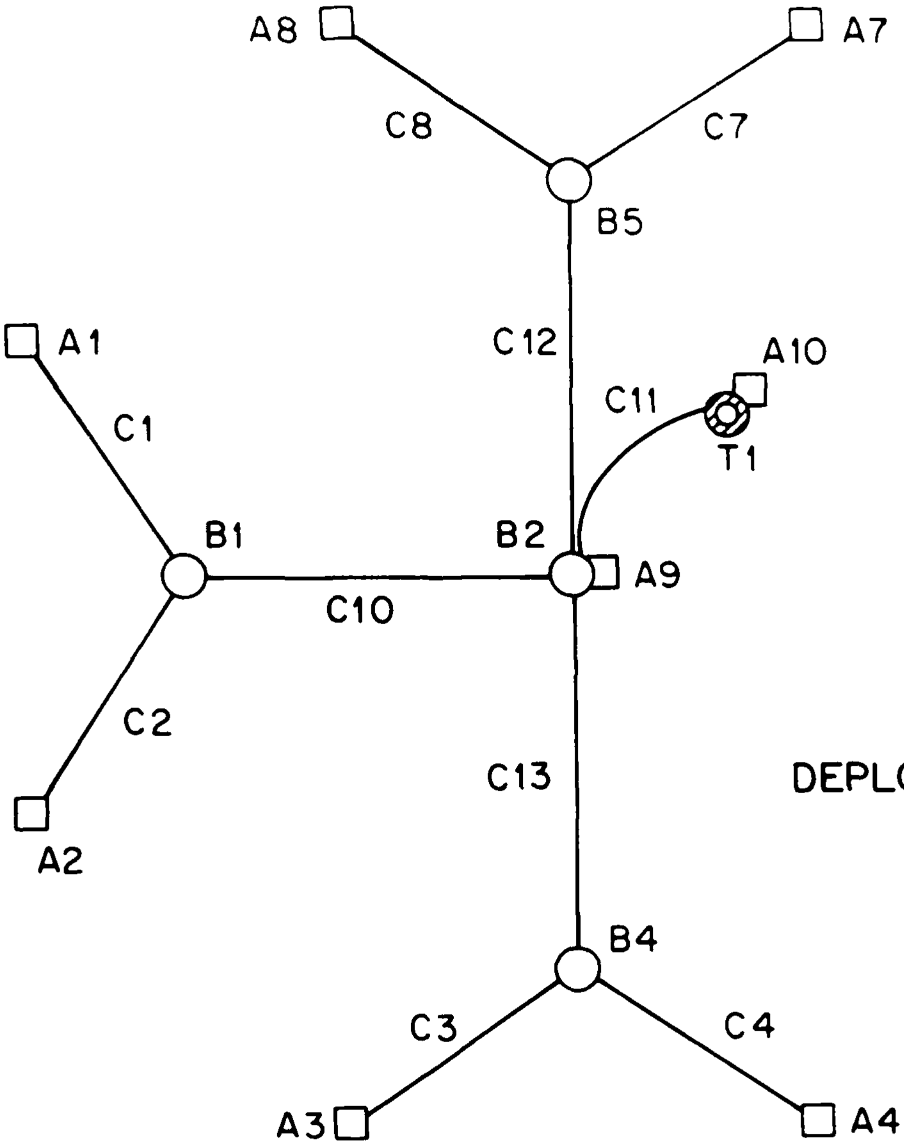
Figure 30

DEPLOYMENT SCENARIO
PHASE III



17. ATTACH C9 TO B2
18. PAYOUT C9
19. LOWER A9 TO POS.9

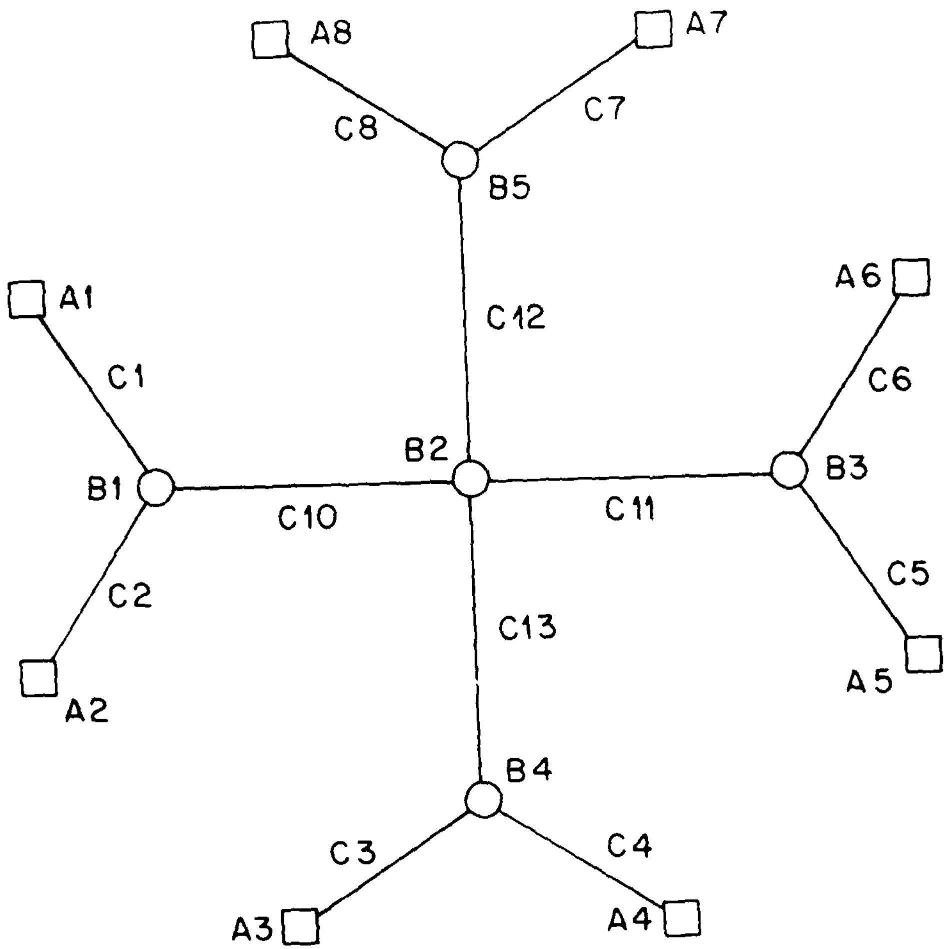
Figure 31



20. ATTACH C7 TO B5
21. PAYOUT C7
22. LOWER A7 TO POS.7
23. ATTACH C4 TO B4
24. PAYOUT C4
25. LOWER A4 TO POS.4

DEPLOYMENT SCENARIO
PHASE IV

Figure 32



DEPLOYMENT SCENARIO
PHASE V

26. REMOVE C11 FROM T1
27. ATTACH B3 TO C11
28. ATTACH C5 AND PAYOUT
29. LOWER A5 TO POS 5
30. ATTACH C6 TO B3
31. PAYOUT C6
32. LOWER A6 TO POS 6
33. REMOVE T1/A10

Figure 33

PHASE 1. The workboat is launched first. The center Buoy B2 is then put overboard and cable C12 attached to it. The vessel then proceeds toward anchor location A8 while paying out the cable. During this time the workboat should hold Buoy B2 in position. When the end of C12 is reached Buoy B5 is attached to C12, cable C8 is attached to B5, and B5 is put overboard. The vessel then proceeds towards anchor position A8 paying out C8. When the end of C8 is reached the anchor A8 is attached to C8 and lowered to the sea floor using the ship's crown line. A transponding acoustic release is inserted between the anchor and the end of the crown line. The transponder is used to obtain ranges from the anchor to the vessel and to the bottom mounted transponders. With this information the anchor can be lowered to its precise location by controlling the winch payout rate and the vessel position. When the anchor has reached its location the acoustic release is fired and the crown line recovered. The vessel then returns to Buoy B2, attached cable C13 to the buoy, deploys C13 and attaches buoy B4 at its end. Cable C3 is then attached to B4, and B4 is put overboard. The vessel then deploys C3, attaches the anchor A3 at the end of C3, and lowers A3 to its prescribed location again using the crown line. At this time Buoys B5, B2, B4 are all on the surface, as shown in Figure 28 (buoys on the surface are shown cross hatched).

After deployment of anchor A3, the vessel hauls back the crown line and proceeds back to Buoy B2. It then attaches cable C11 to this buoy, pays C11 out while steaming towards the surface mooring Buoy T1. It then temporarily attaches the end of C11 to T1.

PHASE 2. The next phase involves setting Buoy B1 and its two anchoring lines C1 and C2, and deploying cable C10 between buoys B1 and B2. The step-by-step procedure is summarized in Figure 29.

PHASE 3. Phase 3 consists in setting the center Buoy B2 in position. The steps involved are shown in Figure 30. At the end of Phase 3 Buoys B1 and B2 are installed.

PHASE 4. In Phase 4 the second anchoring lines of end buoys B4 and B5 are deployed and their anchors set in place following the steps shown in Figure 31. With the completion of this phase, four out of the five buoys of the array are installed.

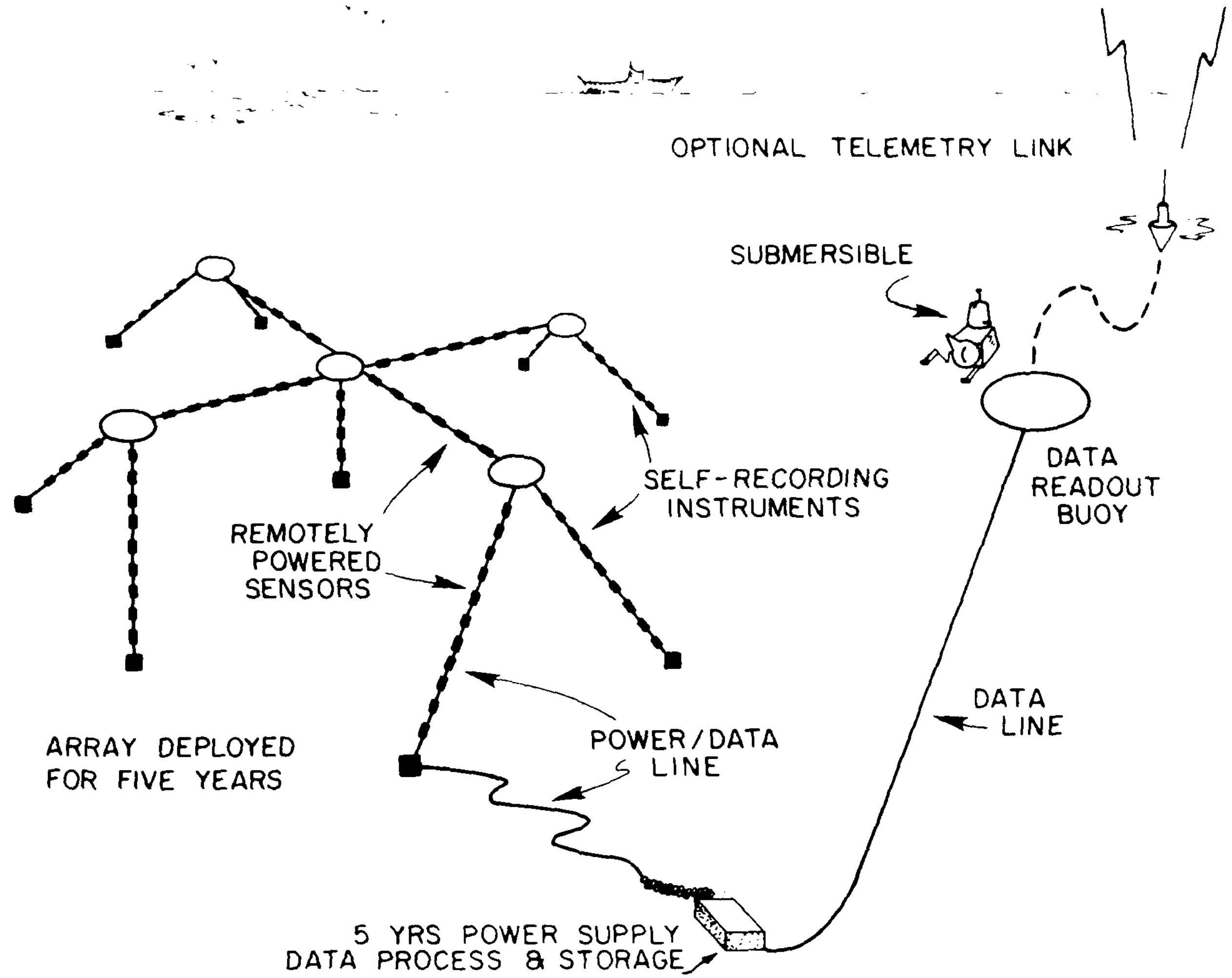
PHASE 5. Phase 5 completes the array deployment. Figure 32 shows the deployed array after C11 has been removed from the surface mooring buoy, attached to Buoy B3 and the anchors attached to C5 and C6 lowered into position. All buoys are now 500 meters below the surface.

The temporary mooring T1 and the acoustic transponder mooring are next recovered. This completes the deployment procedure.

6.2 ARRAY SERVICING

6.2.1 POWERING THE ARRAY

Instruments within the array may be self-contained with internal batteries for power or they may be powered from the array. In the latter case two schemes are considered. In the first, shown in Figure 34, the power supply is set on the bottom near the array and the



— ARRAY SERVICE SCHEME I — WITH FIVE YEAR POWER SUPPLY AND DATA STORAGE ON THE BOTTOM. DATA RETRIEVAL WITH SUBMERSIBLE OR TELEMETRY FROM DATA READOUT BUOY

Figure 34

power line connects to one leg. The power source is visualized as having a five year life using radio-isotopes for power generation.

The second scheme uses a power source which will last for one year. It is located in a service subsurface buoy which is attached to a cable feeding one leg of the array, Figure 35. The power source can be replaced by bringing the subsurface buoy to the surface.

The power leg and all horizontal elements of the array contain power conductors and a signal cable. Array elements connect together at the buoys using special electromechanical connectors. Breakouts are provided along each horizontal cable for the attachment and powering of instruments.

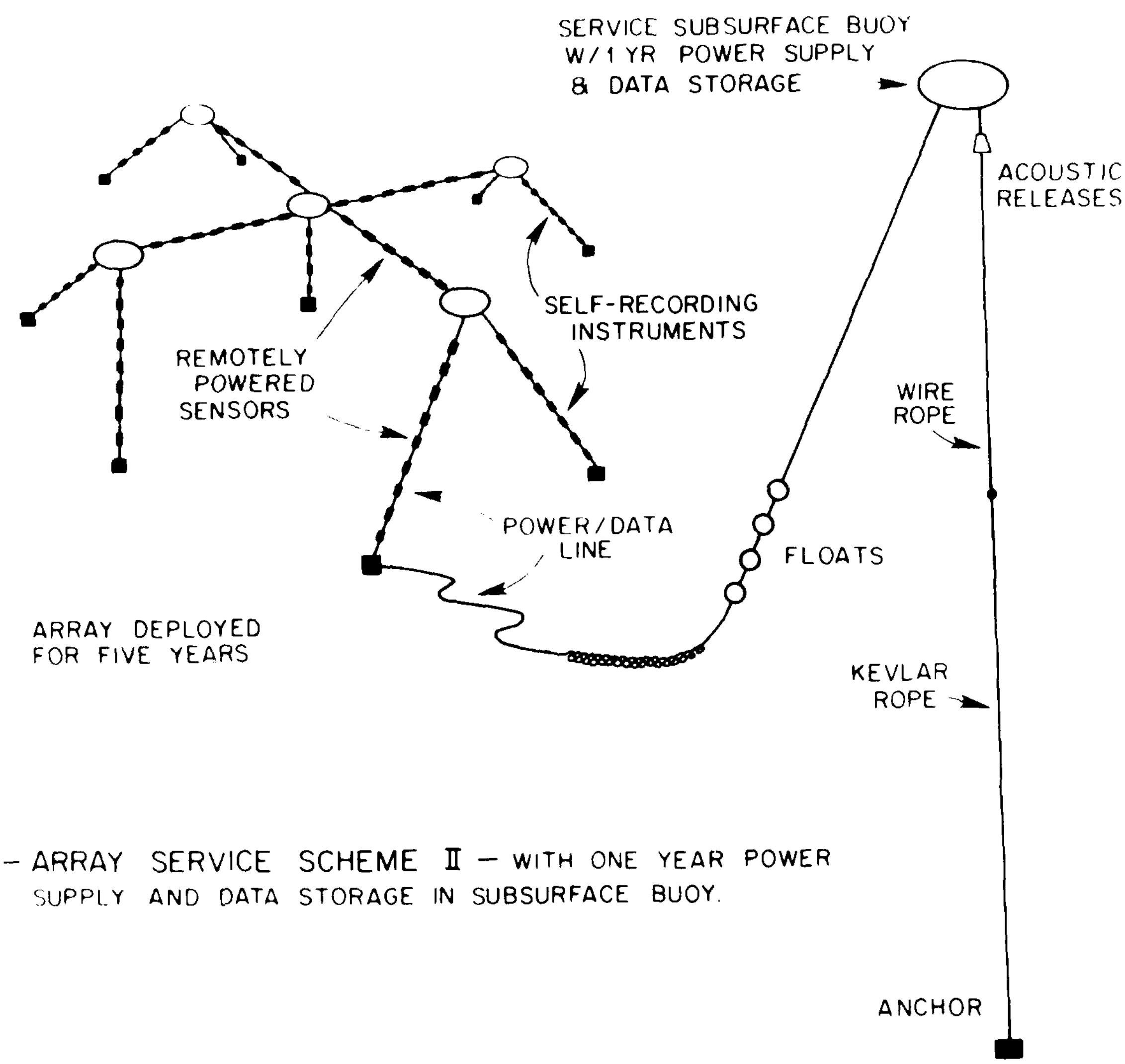
6.2.2 METHODS OF DATA STORAGE AND RETRIEVAL

Autonomous instruments will record their own data internally. The instrument must be recovered in order to obtain the data. On the other hand instruments may be connected into the cable to both obtain power and to communicate data to a central data processing and storage unit. Figures 34 and 35 show schemes for data storage and readout. In both instances the data can be read out from the subsurface buoy by a radio telemetry buoy link or by using an optical system wherein a submersible connects up to the subsurface buoy and dumps the data at a high rate. In the scheme using the service subsurface buoy the data tapes can be recovered when the buoy is brought to the surface.

6.2.3 MODES OF SERVICING

a. Submersibles. Instruments can be removed or replaced from the array using an unmanned or manned submersible. A submersible can best handle a package which is small and nearly neutrally buoyant. A tethered vehicle could be adapted for this service. A submersible could also be used to read out stored data from a subsurface buoy as mentioned above. The vehicle can make periodic inspections of the array to observe corrosion, fouling, strumming and other mechanical aspects of its operation.

b. Surface Ship. A surface ship will be required to replace the power supply and to obtain the data tapes for the system shown in Figure 35. The service subsurface buoy in this configuration contains the power supply and data storage which must be replaced yearly. In order to service the array the surface vessel must first fire the acoustic release below the service subsurface buoy. This permits the leg to fall to the bottom causing the buoy to rise to the surface. The vessel should then take the buoy aboard, holding position accurately and attach a replacement buoy to the array power.data line. A new outboard leg should be attached to the replacement acoustic releases. The buoy is then put overboard and the vessel steams away from the array paying out this leg. A new anchor should be attached at the end. The vessels crown line and an acoustic release should then be attached to the anchor which is put overboard and lowered to the bottom to its anchor position. This anchor position will be determined by the depth of the service subsurface buoy. The acoustic release at the end of the crown line is then fired and the line retrieved.



– ARRAY SERVICE SCHEME II – WITH ONE YEAR POWER SUPPLY AND DATA STORAGE IN SUBSURFACE BUOY.

Figure 35

7.0 COST ESTIMATE OF PROTOTYPE ARRAY COMPONENTS

The following is an estimate of the cost in 1980 dollars of the prototype array structural components. The estimate is based on quotations provided by manufacturers and/or on extrapolation of hardware known prices. The estimate does not include the cost of the bottom cable nor the cost of the service subsurface buoy and its anchoring line(s). Cost of array deployment is also not included.

The cost breakdown of the prototype array components is hereafter tabulated.

ITEM	REQUIRED	DESCRIPTION	PRICE EACH ($1000)	TOTAL
1	5	8.5 ft Diameter Syntactic Foam Buoy	65	325
2	4	5000 meters of ZYTEL coated E/M Kevlar cable	49.25	197
3	1	6166 Meters of E/M Kevlar cable (2000 meters ZYTEL coated)	60.6	60.6
4	7	6106 Meters of Kevlar rope (2000 meters ZYTEL coated)	46.5	325.3
5	1	5000 meters of Kevlar rope (1500 meters ZYTEL coated)	36.6	36.6
6		17,500 lbs Porcupine Cast Iron Anchors	4.5	40.5

TOTAL $985K

Thus the cost of the prototype array components is estimated at $985,000 (1980) U. S. dollars.

8.0 CONCLUSION

It appears feasible to design and deploy large cable structures in deep oceanic basins. These cable arrays can be instrumented to perform a large variety of oceanographic measurements. Proper selection of array structural components will insure a five year working life. Schemes can be devised to power and service such a cable array using an auxiliary mooring.

Many array configurations have been considered in this report. One candidate with good stability characteristics and good scientific potential was retained for further analysis. A detail design of this prototype array was made and its operational effectiveness and its component cost were evaluated. Methods of array installation and servicing were outlined in detail.

Definite specifications as to array objectives and stability tolerances would be required to design a finely tuned array. The possibility of using two stable arrays spaced a few hundred kilometers apart is an interesting one.

REFERENCES

1. Savage, G. H. and Hersey, J. B., 1968. Project Seaspider: The design, assembly, construction and sea trials of a tri-moored buoyant structure with neutrally buoyant legs to provide a near-motionless instrument base for oceanographic research. Woods Hole Oceanographic Institution, Technical Report WHOI-68-42.

2. Sniffin, G. N. and Savage, G. H., 1968. Analysis of the Motion of a Tri-Moored Buoy with Neutrally Buoyant Legs. University of New Hampshire Engineering Design and Analysis Laboratory, Technical Report No. 104.

3. Skop, R. A. and Kaplan, R. E., 1969. The static configuration of a tri-moored, subsurface, buoy-cable array acted upon by current-induced forces. Naval Research Laboratory Report 6894.

4. Dahlen, J. M., 1970. Oceanic Telescope Engineering Program. C. S. Draper Laboratories Technical Report No. E2367.

5. Skop, R. A. and O'Hara, G. J., 1972. A method for the analysis of internally redundant structural cable arrays. Marine Technology Society Journal Vol. 6 No. 1.

6. Walden, R. G. and Berteaux, H. O., 1974. Design and performance of a deep-sea tri-moor. Proceedings Marine Technology Society, Tenth Annual Conference.

7. Panicker, N. N. and Schmidt, D. W., 1975. Prediction and measurement of the stability of the IWEX tripod mooring. Woods Hole Oceanographic Institution, Technical Report No.75-46.

8. Project Linear Chair Array System, 1977. Naval Ocean Research and Development Activity, NORDA Technical Note II.

9. King, P. C. and Swenson, R. C., 1977. The moored acoustic buoy system. Marine Technology Society Journal, Vol. 10, No. 8, p. 14-20.

10. Skop, R. A. and J. Mark, 1973. A Fortran IV Program for Computing the Static Deflections of Structural Cable Arrays. NRL, Report 7640.

11. Prindle, Bryce and R. G. Walden. Deep-Sea Lines Fishbite Manual. 1976. NDBO Report.

12. Bradley, K. The Woods Hole Mace Anchor. EXPOSURE, Volume 8 No.5, November 1980.

Appendix: "DESADE Computer Program Output"

PHYSICAL CHARACTERISTICS OF THE STRUCTURAL CABLE ARRAY
CROSS ARRAY II - DESIGN RUNS.

NO. OF ANCHORS IS 9

JUNCTION NO.	X-COORDINATE	Y-COORDINATE	Z-COORDINATE
[illegible]	.00	.00	.00
[illegible]	.00	19686.00	.00
3	13124.00	32810.00	.00
4	32810.00	32810.00	.00
[illegible]	45934.00	19686.00	.00
6	45934.00	.00	.00
7	32810.00	-13124.00	.00
8	13124.00	-13124.00	.00
9	22967.00	9843.00	.00

NO. OF JUNCTIONS IN ORIGINAL ARRAY IS 14

NO. OF CUTS MADE IN ORIGINAL ARRAY IS 8

JUNCTION NO. OF CUT	JUNCTION NO. AT WHICH CUT MADE
15	2
16	3
17	4
18	5
19	6
20	7
21	8
22	9

NO. OF CABLES IS 13

CABLE NO.	SEC JUNC	SEL JUNC	LENGTH	DIAMETER	WEIGHT/LENGTH	DRAG COEFFICIENT	RIGIDITY	CONSTITUTIVE EXPONENT	NO. OF ELEMENTS
1	1	[illegible]	20225.0	.750	-.057	1.200	1659150.	1.000	20
2	10	15	20225.0	.750	-.057	1.200	1659150.	1.000	20
3	13	16	20225.0	.750	-.057	1.200	1659150.	1.000	20
4	13	17	20225.0	.750	-.057	1.200	1659150.	1.000	20
5	12	18	20225.0	.750	-.057	1.200	1659150.	1.000	20
6	12	19	20225.0	.750	-.057	1.200	1659150.	1.000	20
7	14	20	20225.0	.750	-.057	1.200	1659150.	1.000	20
8	14	21	20225.0	.750	-.057	1.200	1659150.	1.000	20
9	11	22	16000.0	.750	-.057	1.200	1659150.	1.000	20
10	10	11	16240.0	.750	-.057	1.200	1659150.	1.000	20
11	11	12	16240.0	.750	-.057	1.200	1659150.	1.000	20
12	11	14	16240.0	.750	-.057	1.200	1659150.	1.000	20
13	11	13	16240.0	.750	-.057	1.200	1659150.	1.000	20

PROPERTIES OF THE DEVICES LOCATED AT JUNCTIONS ARE AS FOLLOWS

DEVICE JUNC. NO.	DEVICE WEIGHT	DEVICE DRAG COEFFICIENT	DEVICE FRONTAL AREA
[illegible]	10000.00	.500	38.50
11	10000.00	.500	38.50
[illegible]	10000.00	.500	38.50
[illegible]	10000.00	.500	38.50
[illegible]	10000.00	.500	38.50

TOTAL NO. OF INDEXED DEVICES IS 5

CURRENT FIELD OPTION IS 1

Z-COORDINATE OF CURRENT	VELOCITY OF CURRENT AT Z
.00	.5[illegible]
9843.00	.5[illegible]
13124.00	.3[illegible]
16405.00	.6[illegible]
[illegible]	.6[illegible]

ACCURACY REQUIRED IN CALCULATIONS IS 30.00

ARRAY EQUILIBRIUM WITH NØ CURRENT

ARRAY ANCHØRS
----- -------

JUNC. NØ. ØF ANCHØR	CABLE AT ANCHØR	TENSIØN AT ANCHØR	FØRCE CØMPØNENTS AT ANCHØR X-CØMP	Y-CØMP	Z-CØMP	HØR.-CØMP	CABLE ANGLES WRT X-AXIS	XY-PLANE
1	1	4682.9	1704.9	2487.7	3582.6	3015.8	55.58	49.91
2	2	4684.0	1705.3	-2487.9	3583.6	3016.2	-55.57	49.91
3	3	4683.4	2487.8	-1705.0	3583.0	3016.0	-34.43	49.91
4	4	4683.6	-2487.8	-1705.1	3583.2	3016.1	-145.57	49.91
5	5	4683.6	-1705.1	-2487.8	3583.2	3016.1	-124.43	49.91
6	6	4683.4	-1705.1	2487.8	3583.0	3016.0	124.43	49.91
7	7	4683.5	-2487.8	1705.1	3583.1	3016.1	145.57	49.91
8	8	4683.5	2487.8	1705.1	3583.1	3016.1	34.43	49.91
9	9	7498.0	.0	.1	7498.0	.1	67.53	90.00

ARRAY CABLES
----- ------

CABLE NØ.	MAXIMUM TENSIØN	S-CØØRD ØF	MINIMUM TENSIØN	S-CØØRD ØF	MAXIMUM DISP.	S-CØØRD ØF	LØCATIØN ØF THIS PØINT X-CØØRD	Y-CØØRD	Z-CØØRD	NØ CURRENT LØC. ØF THIS PØINT X-CØØRD	Y-CØØRD	Z-CØØRD
1	[illegible]	[illegible]	4682.9	[illegible]								
2	5615.3	[illegible]	4684.0	20225.[illegible]								
3	[illegible]	[illegible]	4683.4	20225.[illegible]								
4	[illegible]	[illegible]	4683.6	20225.								
5	[illegible]	[illegible]	4683.6	20225.[illegible]								
6	[illegible]	[illegible]	4683.4	20225.[illegible]								
7	[illegible]	[illegible]	4683.5	[illegible]								
8	[illegible]	[illegible]	4683.5	20225.[illegible]								
9	[illegible]	[illegible]	[illegible]	[illegible]								
10	[illegible]	[illegible]	[illegible]	9265.8								
11	[illegible]	[illegible]	[illegible]	[illegible]								
12	[illegible]	[illegible]	[illegible]	[illegible]								
13	[illegible]	[illegible]	[illegible]	[illegible]								

ARRAY JUNCTIØNS
----- ---------

	JUNC. NØ.	CABLE AT JUNCTIØN	TENSIØN AT JUNCTIØN	CABLE ANGLES WRT X-AXIS	XY-PLANE	JUNCTIØN LØCATIØN X-CØØRD	Y-CØØRD	Z-CØØRD	DISPLACEMENT FRØM NØ CURRENT LØC. X-DISP	Y-DISP	Z-DISP
Buoy #1	10	[illegible]	[illegible]	[illegible]	-57.51	6746.3	9843.9	16388.1			
	10	[illegible]	[illegible]	124.43	-57.51						
	10	[illegible]	[illegible]	[illegible]	-8.80						
Buoy #2	11	[illegible]	[illegible]	[illegible]	-90.00	22967.1	9843.1	16079.3			
	11	[illegible]	3433.3	180.00	-6.65						
	11	11	3433.3	.00	-6.65						
	11	12	3433.4	-90.00	-6.65						
	11	13	3433.3	90.00	-6.65						
Buoy #3	12	5	5614.8	55.57	-57.51	39187.8	9843.2	16388.1			
	12	6	5614.7	-55.57	-57.51						
	12	11	3450.9	-180.00	-8.80						
Buoy #4	13	3	5614.6	145.57	-57.51	22967.2	26063.8	16388.1			
	13	4	5614.9	34.43	-57.51						
	13	13	3450.8	-90.00	-8.80						
Buoy #5	14	7	5614.8	-34.43	-57.51	22967.1	-6377.7	16388.0			
	14	8	5614.8	-145.57	-57.51						
	14	12	3450.9	90.00	-8.80						

ARRAY [illegible] CURRENT [illegible] .00 DEGREES

ARRAY ANCHORS

JUNC. NO. OF ANCHOR	CABLE AT ANCHOR	TENSION AT ANCHOR	FORCE COMPONENTS AT ANCHOR X-COMP	Y-COMP	Z-COMP	HOR.-COMP	CABLE ANGLES WRT X-AXIS	XY-PLANE
1	1	4828.9	2081.6	2534.1	3544.5	3279.4	50.60	47.22
2	2	4828.6	2081.4	-2534.0	3544.2	3279.3	-50.60	47.22
3	3	5804.4	3105.4	-2086.4	4437.9	3741.2	-33.90	49.87
4	4	3593.5	-1886.1	-1372.6	2733.5	2332.7	-143.96	49.52
5	5	4575.6	-1337.0	-2455.0	3622.3	2795.4	-118.57	52.34
6	6	4575.6	-1337.0	2455.0	3622.3	2795.5	118.57	52.34
7	7	3593.5	-1886.1	1372.6	2733.4	2332.7	143.96	49.52
8	8	5804.4	3105.4	2086.3	4437.9	3741.1	33.89	45.97
9	9	7506.9	574.1	-.0	7484.9	574.1	-.00	85.61

ARRAY CABLES

CABLE NO.	MAXIMUM TENSION	S-COORD OF	MINIMUM TENSION	S-COORD OF	MAXIMUM DISP.	S-COORD OF	LOCATION OF THIS POINT X-COORD	Y-COORD	Z-COORD	NO CURRENT LOC. OF THIS POINT X-COORD	Y-COORD	Z-COORD
1	5734.4	20225.0	4828.9	.0	1086.5	20225.0	7735.6	9842.9	15938.8	6746.3	9843.9	16388.1
2	5734.0	.0	4828.6	20225.0	1086.5	.0	7735.6	9842.9	15938.8	6746.3	9843.9	16388.1
3	6733.0	.0	5804.4	20225.0	90.8	.0	22995.6	25984.2	16354.9	22967.2	26063.8	16388.1
4	4523.4	.0	3593.5	20225.0	133.0	6067.5	25808.9	27851.4	11294.8	25736.5	27761.9	11310.5
5	5528.0	.0	4575.6	20225.0	1053.2	.0	40171.8	9843.0	16763.5	39187.8	9843.2	16388.1
6	5528.0	.0	4575.6	20225.0	1053.2	.0	40171.8	9843.0	16763.5	39187.8	9843.2	16388.1
7	4523.4	.0	3593.5	20225.0	133.1	6067.5	25808.9	-8165.3	11294.9	25736.4	-8275.4	11310.4
8	6732.9	.0	5804.4	20225.0	90.8	.0	22995.6	-6298.1	16355.0	22967.1	-6377.7	16388.0
9	8417.0	.0	7516.9	16000.0	1000.6	.0	23967.1	9843.1	16044.8	22967.1	9843.1	16079.3
10	3672.2	16240.0	3649.8	7712.3	1086.5	.0	7735.6	9842.9	15938.8	6746.3	9843.9	16388.1
11	3399.9	16240.0	3344.3	5527.5	1053.2	16240.0	40171.8	9843.0	16763.5	39187.8	9843.2	16388.1
12	3574.3	16240.0	3534.6	6911.7	1191.6	4872.0	24158.5	4980.0	15694.1	22967.1	4976.4	15710.3
13	3574.3	16240.0	3534.7	6911.8	1191.5	4872.0	24158.5	14706.1	15694.1	22967.1	14709.4	15710.4

ARRAY JUNCTIONS

JUNC. NO.	CABLE AT JUNCTION	TENSION AT JUNCTION	CABLE ANGLES WRT X-AXIS	XY-PLANE	JUNCTION LOCATION X-COORD	Y-COORD	Z-COORD	DISPLACEMENT FROM NO CURRENT LOC. X-DISP	Y-DISP	Z-DISP
10	1	5734.4	-125.29	-56.49	7735.6	9842.9	15938.8	989.3 (302 m.)	-1.0	-449.3
10	2	5734.0	125.28	-56.49						
10	10	3666.2	.00	-6.85						
11	9	8417.0	180.00	-87.84	23967.1	9843.1	16044.8	1000.0	-.0	-34.4
11	10	3672.2	-180.00	-7.66						
11	11	3359.1	-.00	-5.36						
11	12	3556.7	-85.17	-6.34						
11	13	3556.8	85.18	-6.34						
12	5	5528.0	55.39	-58.05	40171.8	9843.0	16763.5	984.0	-.2	375.4
12	6	5528.0	-55.39	-58.05						
12	11	3399.9	180.00	-10.49						
13	3	6733.0	143.38	-57.93	22995.6	25984.2	16354.9	28.4	-79.6	-33.2
13	4	4523.4	32.05	-56.44						
13	13	3574.3	-78.48	-8.44						
14	7	4523.4	-32.05	-56.44	22995.6	-6298.1	16355.0	28.6	79.6	-33.0
14	8	6732.9	-143.38	-57.93						
14	12	3574.3	78.48	-8.44						

ARRAY EQUILIBRIUM WITH CURRENT FROM 45.00 DEGREES

ARRAY ANCHORS

JUNC. NO. OF ANCHOR	CABLE AT ANCHOR	TENSION AT ANCHOR	FORCE COMPONENTS AT ANCHOR X-COMP	Y-COMP	Z-COMP	HOR.-COMP	CABLE ANGLES WRT X-AXIS	XY-PLANE
1	1	5383.1	2150.7	2859.3	4022.0	3577.9	53.05	48.34
2	2	4173.0	1746.3	-2166.5	3109.7	2782.7	-51.13	48.18
3	3	5341.1	2880.0	-1686.2	4170.1	3337.3	-30.35	51.33
4	4	3869.5	-2056.5	-1270.4	3021.6	2417.3	-148.29	51.34
5	5	3872.4	-1271.5	-2057.7	3024.0	2418.8	-121.71	51.34
6	6	5339.1	-1665.7	2879.3	4168.2	3336.4	120.35	51.32
7	7	4172.9	-2166.5	1746.5	3109.6	2782.8	141.13	48.17
8	8	5383.9	2859.7	2151.2	4022.6	3578.5	36.95	48.34
9	9	7492.1	356.2	356.5	7475.1	503.9	45.02	86.14

ARRAY CABLES

CABLE NO.	MAXIMUM TENSION	S-COORD OF	MINIMUM TENSION	S-COORD OF	MAXIMUM DISP.	S-COORD OF	LOCATION OF THIS POINT X-COORD	Y-COORD	Z-COORD	NO CURRENT LOC. OF THIS POINT X-COORD	Y-COORD	Z-COORD
1	[illegible]	20225.0	5383.1	.0	679.2	20225.0	7367.8	9859.5	16114.6	6746.3	9843.9	16389.1
2	5058.9	.0	4173.0	20225.0	679.6	203.4	7307.1	9954.9	15944.8	6684.3	9934.6	16216.0
3	6284.8	.0	5341.1	20225.0	613.8	233.6	22884.6	26706.4	16413.8	22863.3	26135.1	16190.6
4	4814.4	.0	3869.5	20225.0	613.1	.0	22983.7	26633.8	16613.5	22967.2	26063.8	16388.1
5	4816.7	.0	3872.4	20225.0	612.5	.0	39757.2	9860.8	16613.2	39187.8	9843.2	16388.1
6	6282.2	.0	5339.1	20225.0	613.1	233.2	39829.6	9761.9	16413.8	39258.9	9739.4	16190.8
7	5088.5	.0	4172.9	20225.0	680.4	203.2	23079.0	-5816.3	15944.3	23057.5	-6439.7	16216.1
8	6299.0	.0	5383.9	20225.0	679.9	.0	22983.8	-5755.7	16114.0	22967.1	-6377.7	16388.0
9	8402.7	.0	7492.1	16000.0	859.0	.0	23573.9	10450.5	16052.8	22967.1	9843.1	16079.3
10	3559.6	.0	3528.0	8490.6	903.4	12356.9	-19702.0	10503.8	15677.2	19090.4	9843.3	15753.3
11	3479.5	16740.0	3429.7	6212.3	932.0	4872.0	28444.4	10545.8	15757.9	27833.7	9843.1	15710.3
12	3560.5	16740.0	3528.5	7805.2	903.5	3424.6	-23628.0	7037.0	15708.3	22967.1	6425.1	15778.8
13	[illegible]	16740.0	3430.6	6110.8	931.5	4872.0	23668.4	15321.0	15757.9	22967.1	14709.5	15710.4

ARRAY JUNCTIONS

JUNC. NO.	CABLE AT JUNCTION	TENSION AT JUNCTION	CABLE ANGLES WRT X-AXIS	XY-PLANE	JUNCTION LOCATION X-COORD	Y-COORD	Z-COORD	DISPLACEMENT FROM NO CURRENT LOC. X-DISP	Y-DISP	Z-DISP
10	1	6298.4	-126.32	-57.27	7367.8	9859.5	16114.6	621.5	15.7	-273.5
10	2	5058.9	122.34	-56.38						
10	10	3559.6	5.70	-7.49						
11	9	8402.7	-134.45	-86.32	23573.9	10450.5	16052.8	606.8	607.4	-26.5
11	10	3556.2	178.13	-7.43						
11	11	3447.7	2.40	-5.67						
11	12	3556.9	-88.13	-7.43						
11	13	3448.1	87.61	-5.67						
12	5	4816.7	56.80	-57.03	39757.2	9860.8	16613.2	569.4	17.6	225.1
12	6	6282.2	-53.63	-58.45						
12	11	3479.5	172.63	-10.02						
13	3	6284.8	143.63	-58.46	22983.7	26633.8	16613.5	16.5	570.0	225.4
13	4	4814.4	33.20	-57.02						
13	13	3480.0	-82.61	-10.01						
14	7	5088.5	-32.35	-56.38	22983.8	-5755.7	16114.0	16.7	622.0	-274.0
14	8	6299.0	-143.68	-57.27						
14	12	3560.5	84.29	-7.49						

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A FEASIBILITY STUDY FOR A VERSATILE DEEP SEA, MULTILEG, STABLE, CABLE ARRAY by Henri O. Berteaux and Robert G. Walden. 72 pages. March 1981. Prepared for the Office of Naval Research under Contract N00014-79-C-0894.

The purpose of this study is to investigate the feasibility of designing, building, and deploying a large, stable, multileg, deep ocean cable array with a service life of at least five years, and to assess the cost of such an array.

The study first defines the essential desirable features of the array. It then briefly describes a number of candidate configurations which can meet these requirements, pointing out their advantages and disadvantages.

The report concludes that such an array is feasible, that it can be implanted with a high expectation of reliability and that it can be a safe and stable structure from which to conduct divers novel and useful scientific experiments.

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2. Moorings, multileg
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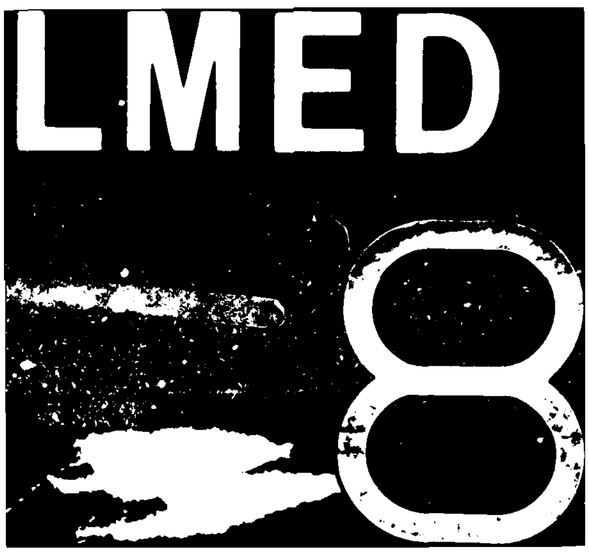
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